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(54) **STYRENIC RESIN INCORPORATING RECYCLED POLYSTYRENE**

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CPC C08F 12/08; C08F 297/00; C08L 25/06; C08L 25/02; C08L 51/003; C08L 2205/02; C08L 2207/20
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(57) **ABSTRACT**

The present disclosure provides a styrenic resin incorporating post-consumer recycle polystyrene (PCR PS), and systems and methods for making the same. For example, a styrenic resin produced in accordance with present embodiments between approximately 1 weight percent and 9 weight percent PCR PS, has a melt flow rate (MFR) of less than approximately 2.0 g/10 min per ASTM D-1238-10, and an Mz+1 molecular weight of at least 700,000. The styrenic resin is produced by a free-radical polymerization process performed on a feed having PCR PS dissolved in monovinylarene monomer. The feed is produced in such a way so as to continuously remove contaminants commonly associated with PCR PS.

20 Claims, 5 Drawing Sheets

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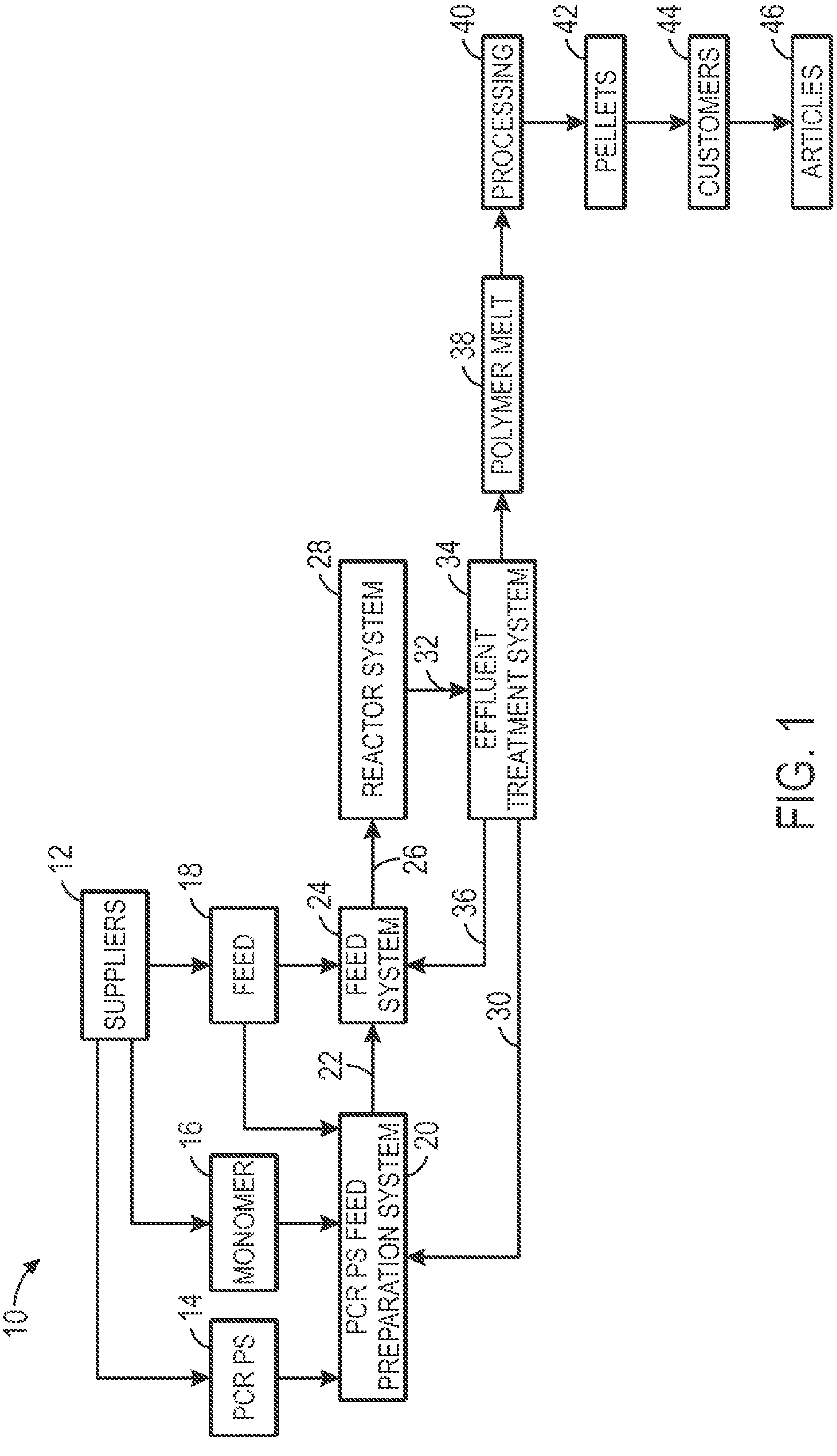
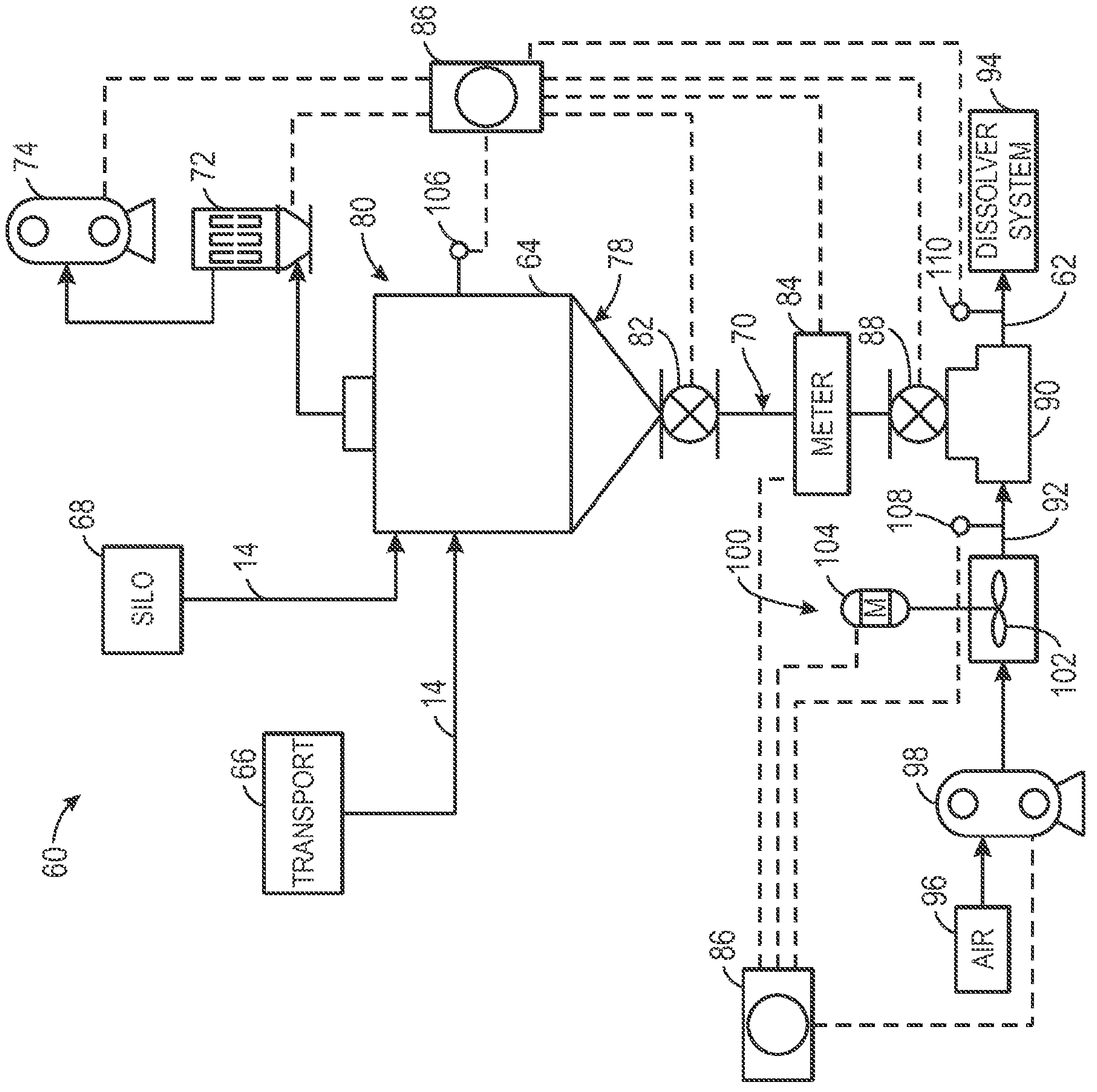

10
12
SUPPLIERS
14
PCR PS
16
MONOMER
18
FEED
20
PCR PS FEED PREPARATION SYSTEM
22
24
FEED SYSTEM
26
28
REACTOR SYSTEM
30
32
34
EFFLUENT TREATMENT SYSTEM
36
38
POLYMER MELT
40
PROCESSING
42
PELLETS
44
CUSTOMERS
46
ARTICLES

FIG. 1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66
TRANSPORT
14
68
SILO
14
80
106
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78
72
74
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82
70
84
METER
88
110
94
DISSOLVER SYSTEM
62
90
92
108
100
104
M
102
98
96
AIR
86

FIG. 2

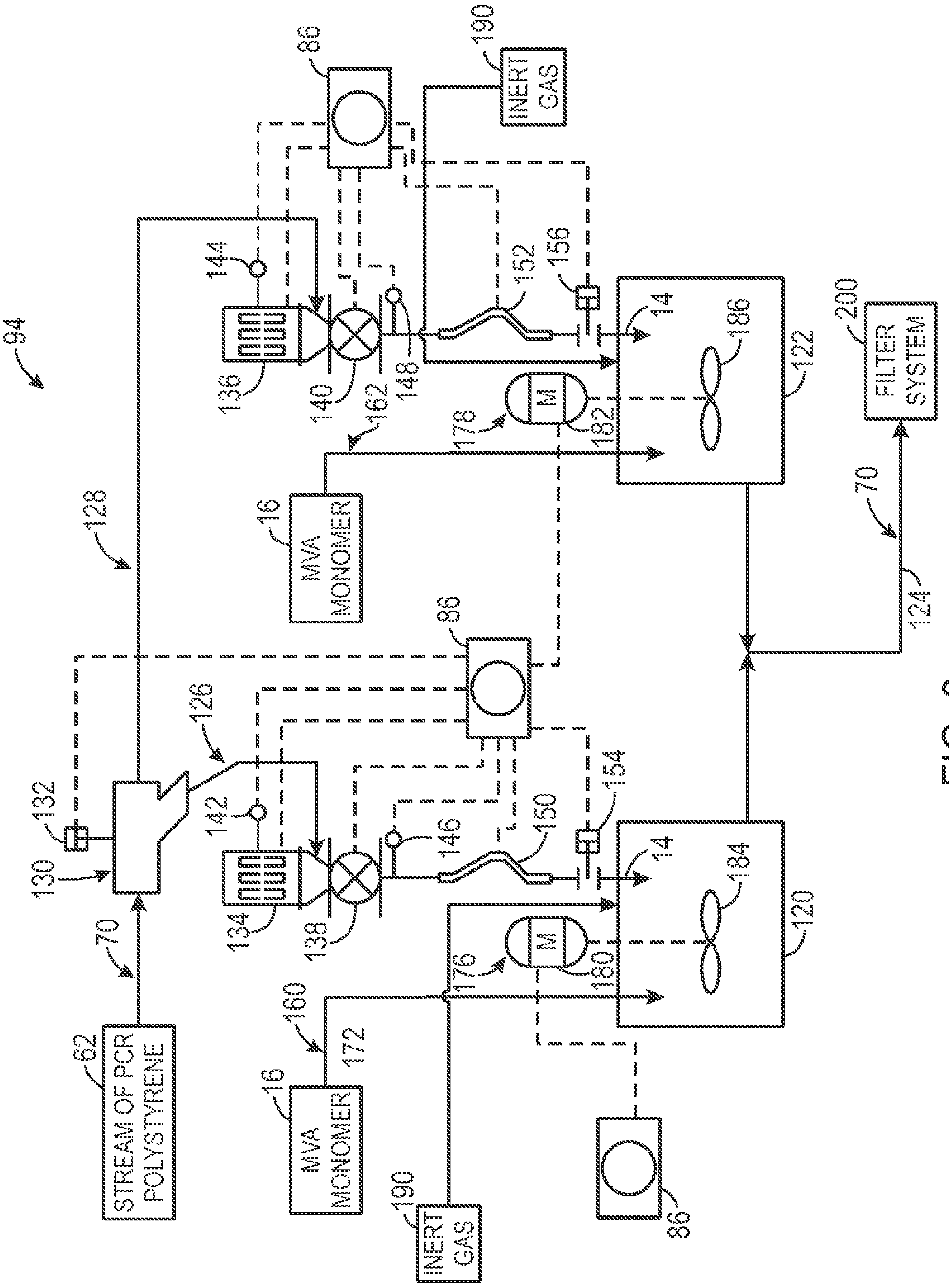
94
STREAM OF PCR POLYSTYRENE
62
70
130
132
126
128
MVA MONOMER
16
160
172
INERT GAS
190
176
M
180
184
120
14
154
150
146
142
134
138
86
86
86
136
140
144
162
148
152
156
MVA MONOMER
16
178
M
182
186
122
14
INERT GAS
190
124
70
FILTER SYSTEM
200

FIG. 3

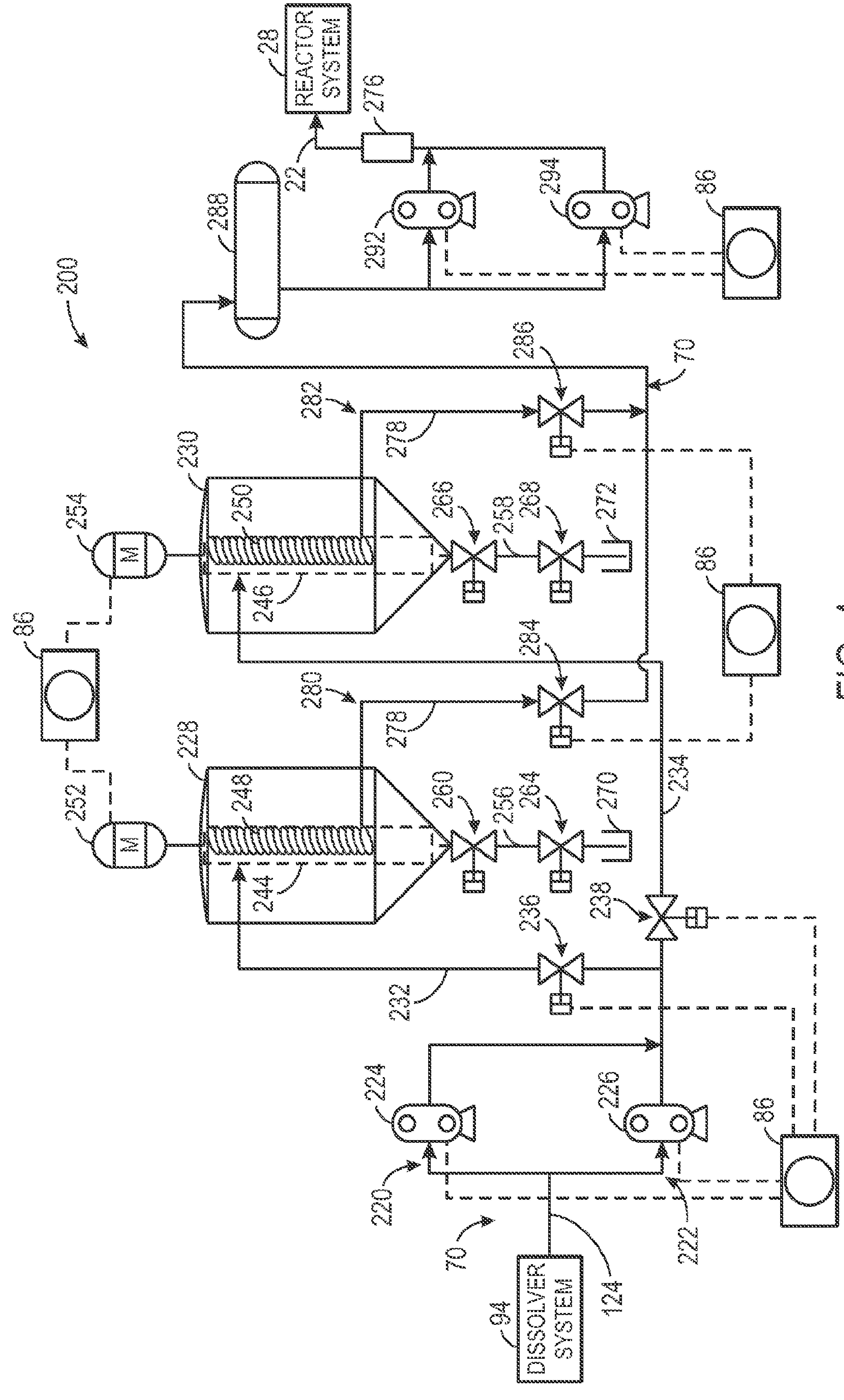
200
28
REACTOR SYSTEM
276
22
288
292
294
86
286
70
282
278
230
254
M
250
266
258
268
272
246
86
86
284
280
278
228
252
M
248
260
256
264
270
244
234
238
236
232
224
226
86
220
222
70
124
94
DISSOLVER SYSTEM

FIG. 4

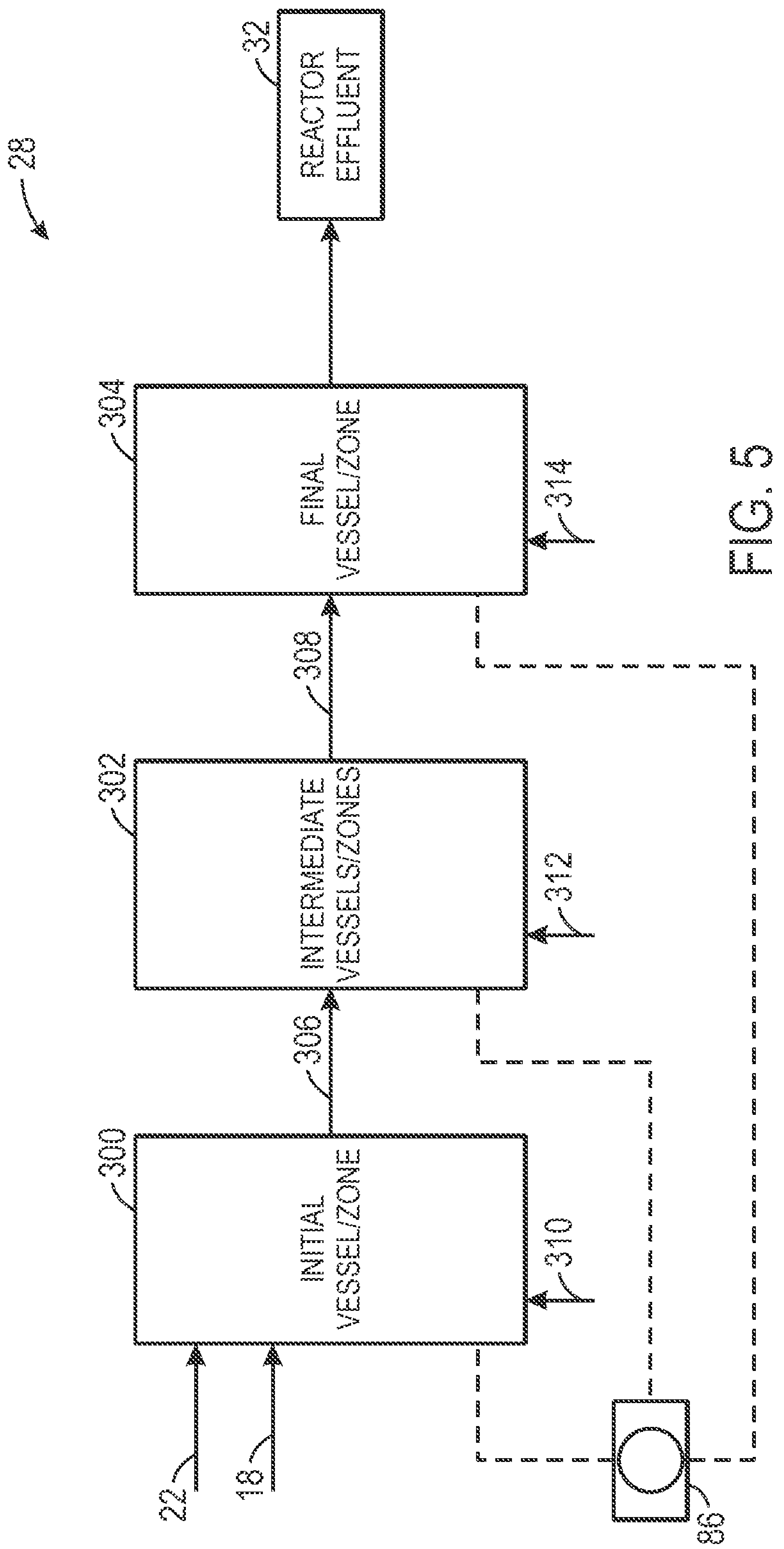
28
32
REACTOR EFFLUENT
304
FINAL VESSEL/ZONE
314
308
302
INTERMEDIATE VESSELS/ZONES
312
306
300
INITIAL VESSEL/ZONE
310
22
18
86

FIG. 5

STYRENIC RESIN INCORPORATING RECYCLED POLYSTYRENE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. patent application Ser. No. 13/571,152 entitled "STYRENIC RESIN INCORPORATING RECYCLED POLYSTYRENE," filed on Aug. 9, 2013, now U.S. Pat. No. 8,609,778, which is hereby incorporated by reference in its entirety for all purposes.

BACKGROUND

The present disclosure relates generally to the field of polymerization and, more specifically, to polystyrene resins.

This section is intended to introduce the reader to various aspects of art that may be related to various aspects of the present disclosure, which are described and/or claimed below. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present disclosure. Accordingly, it should be understood that these statements are to be read in this light, and not as admissions of prior art.

As technologies for producing polymeric materials from simple molecular building blocks (i.e. monomers) have advanced, the products of such techniques, such as plastic goods, have become increasingly prevalent in society. One general class of polymeric materials that has seen widespread use is polystyrene. Because of the number of ways in which it may be processed, polystyrene can take a wide variety of forms and, therefore, is found in a wide variety of markets ranging from food contact applications to electronics. General purpose polystyrene (GPPS), for example, is used in a number of every day products such as jewel cases for electronic storage media (e.g. compact discs, digital video discs), housings for electronic components, laboratory equipment, appliances, toys, food containers, disposable cutlery, foams used in coffee cups and packing materials, and so on.

Due to such widespread use, many millions of tons of polystyrene are produced each year in order to manufacture these and other polystyrene-based products. In the interest of environmental stewardship, it would therefore be advantageous if at least a portion of these polystyrene-based products could be recycled. One general source of polystyrene that could potentially be recycled can be obtained from articles of manufacture used by consumers, also known as post consumer recycled (PCR) material. Unfortunately, a number of variables affect the feasibility of using post consumer material as a recycled material source for polystyrene.

For example, forming a new article partially or entirely from PCR polystyrene is generally very difficult. This difficulty mostly arises from poor processability, which is typically a result of the low molecular weights associated with PCR polystyrene resins compared to virgin polystyrene resins (e.g. resins that have not yet been formed into an article). Because of this low molecular weight, articles formed using PCR polystyrene generally also have relatively poor performance (e.g. strength) and poor appearance (e.g. clarity, color).

Processability, performance, and appearance may also be negatively affected by the presence of other materials often associated with polystyrene-based products. For example, polystyrene-based food containers, beverage containers, and/or disposable utensils may contain residual food. Coat hangers, electronic devices such as computers and household appliances, and electronic housings may include metals and/or other polymeric materials. Other polymeric materials commonly associated with used polystyrene-based articles can include polyethylene, polypropylene, polycarbonate, polybutadiene, polyacrylonitrile, and the like, which can all negatively affect the properties of a polystyrene resin.

Unfortunately, the presence of any one or a combination of these materials, and the poor processability, performance, and appearance generally associated with PCR polystyrene can be a significant hindrance to recycling polystyrene products. Accordingly, a need exists for systems and methods for producing a high quality stream of PCR polystyrene, as well as systems and methods for recycling PCR polystyrene into a resin having processability, performance, and appearance suitable for the production of articles of manufacture.

SUMMARY

A summary of certain embodiments disclosed herein is set forth below. It should be understood that these aspects are presented merely to provide the reader with a brief summary of these certain embodiments and that these aspects are not intended to limit the scope of this disclosure. Indeed, this disclosure may encompass a variety of aspects that may not be set forth below.

The present disclosure relates generally to the recycling of styrenic materials that have been used in consumer products and subsequently returned to a manufacturer for re-use. Such materials, defined herein as "post-consumer recycle polystyrene" (PCR PS), are incorporated into a styrenic feed including the PCR PS dissolved within monovinylarene monomer. As discussed in detail below, a PCR PS feed preparation system including a number of subsystems for receiving, dissolving, and generally cleaning/treating (e.g., filtering) the styrenic feed is provided. Polymerizing the monovinylarene monomer in the feed may produce a post-consumer containing (PCC) styrenic resin. Indeed, as defined herein, a "post-consumer containing" (PCC) styrenic resin is intended to denote a newly produced resin incorporating PCR PS and virgin styrenic polymer.

By producing a resin in this manner, the virgin styrenic resin produced by the polymerization and the PCR PS may become intimately mixed, such that the virgin styrenic material is able to substantially offset the relatively poor properties of the PCR PS. A resin produced in accordance with present embodiments may have, generally, between 1 weight percent and 50 weight percent PCR PS, such as between approximately 1 weight percent and 30 weight percent. In some embodiments, a resin produced in accordance with present embodiments may have less than 10 weight percent but more than 1 weight percent PCR PS, for example between approximately 1 weight percent and 9 weight percent, between approximately 2 weight percent and 8 weight percent PCR PS, between approximately 3 weight percent and 7 weight percent PCR PS, or between approximately 4 weight percent and 6 weight percent PCR PS. Alternatively, the styrenic resin may include at least approximately 10 weight percent and 40 weight percent PCR PS, such as between approximately 20 weight percent and 30 weight percent PCR PS, between approximately 20 weight percent and 26 weight percent PCR PS, or approximately 25 weight percent PCR PS.

The virgin material and control of the polymerization reaction may be sufficient so as to produce the post-consumer styrenic resin with the desired processability and performance, characterized by melt flow rate (MFR), Z+1 molecular weight (Mz+1), and/or extensional viscosity (EV), which may all be characteristic of processability and performance.

Generally, the MFR of the post-consumer styrenic resin will be below 4.0 g/10 min per ASTM D-1238-10, such as 2.5 g/10 min or less per ASTM D-1238-10, or less than 2.0 g/10 min per ASTM D-1238-10. The Mz+1 of the post-consumer styrenic resin may be at least approximately 685,000 atomic mass units (a.m.u.), such as between approximately 680,000 and 750,000 a.m.u. Further, the EV of the post-consumer styrenic resin will generally be at least 250,000 Pascal-seconds (Pa-sec), such as between approximately 285,000 Pa-sec and 350,000 Pa-sec, or between approximately 300,000 Pa-sec and 340,000 Pa-sec.

BRIEF DESCRIPTION OF THE DRAWINGS

Various aspects of this disclosure may be better understood upon reading the following detailed description and upon reference to the drawings in which:

FIG. **1** is a block diagram of one embodiment of a system configured to produce a post-consumer containing styrenic resin from post-consumer recycled polystyrene obtained from one or more sources, in accordance with an aspect of the present disclosure;

FIG. **2** is a diagrammatical illustration of an embodiment of a receiving system of the PCR PS feed preparation system of FIG. **1**, the receiving system being configured to receive the PCR PS and convey the PCR PS in a controlled manner to a dissolver system of the PCR PS feed preparation system, in accordance with an aspect of the present disclosure;

FIG. **3** is a diagrammatical illustration of an embodiment of a dissolver system of the PCR PS feed preparation system of FIG. **1**, the dissolver system being configured to receive the PCR PS and a monovinylarene monomer, and to dissolve the PCR PS in the monovinylarene monomer to produce a dissolved mixture, and to convey the dissolved mixture in a controlled manner to a filter system of the PCR PS feed preparation system, in accordance with an aspect of the present disclosure;

FIG. **4** is a diagrammatical illustration of an embodiment of a filter system of the PCR PS feed preparation system of FIG. **1**, the filter system being configured to receive the dissolved mixture from the dissolver system of the PCR PS feed preparation system of FIG. **1**, to filter the dissolved mixture to produce a filtered mixture, and to produce a PCR PS feed to a reactor system, in accordance with an aspect of the present disclosure; and

FIG. **5** is a block diagram of an embodiment of the reactor system of FIG. **1**, the reactor system being configured to receive the PCR PS feed and/or the reactor feed from the PCR PS feed preparation system of FIG. **1**, the feed system of FIG. **1**, or both, to produce a post-consumer styrenic resin having virgin styrenic resin and PCR PS, in accordance with an aspect of the present disclosure.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

One or more specific embodiments will be described below. In an effort to provide a concise description of these embodiments, not all features of an actual implementation are described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

As noted above, difficulties associated with recycling polystyrene products can include the presence of contaminants (e.g., particulates, non-styrenic polymers, food waste, metals) and prior processing (e.g., heat history, shear) associated with the used polystyrene. These factors can result in poor processability and poor physical properties if the PCR PS is not treated.

Processing, which generally involves exposing a resin to high heat and shear (e.g., during extrusion), can result in chain scission in the polymeric chains of a given resin, effectively reducing the average molecular weight and, therefore, the subsequent processability and performance of the resin. Each cycle of high heat may generally be referred to as a heat history, and is typically associated with a cycle in which the resin is exposed to high shear. Incidentally, each heat history of a resin results in a reduction in the processability, performance, and appearance of the resin.

In view of these factors, it is now recognized that it may be desirable to treat used streams of polystyrene material in a manner that enables the used stream of polystyrene material to be incorporated in a newly produced styrenic resin. For example, it is now recognized that it may be desirable to remove contaminants from the used polystyrene (i.e., a PCR PS) so as to enable its incorporation into a polymerization process configured to produce a virgin styrenic resin. Systems and methods enabling the production of such a stream of PCR PS are discussed in detail below with respect to FIGS. **2**-**4**.

In addition, it is also now recognized that it may be desirable to enhance the processability, performance, and appearance of a resin incorporating PCR PS (i.e., a PCC styrenic resin) by incorporating the PCR PS, along with virgin polystyrene, into a new resin having enhanced processability and performance compared to PCR PS alone. For example, in accordance with certain embodiments, PCR PS that is treated using the systems and methods discussed with respect to FIGS. **2**-**4** may be incorporated as a feed component into a polymerization system configured to produce a virgin polystyrene. Accordingly, the resin produced according to such embodiments may include PCR PS along with the virgin polystyrene produced in the system. The virgin polystyrene produced within the system may, in some embodiments, have enhanced characteristics so as to at least partially offset the negative effects of the PCR PS on processability and performance.

Further, it is now recognized that producing such a resin "in-reactor" (i.e., incorporating the PCR PS into a reactor that then produces a styrenic resin) may produce a styrenic resin having improved properties compared to a resin produced by compounding the PCR PS with a virgin polystyrene resin. Indeed, using the approaches described herein, the present embodiments enable the production of a styrenic resin having at least 5 percent by weight (wt %) PCR PS, such as between approximately 5 and 50 wt %, 15 and 40 wt %, 20 and 30 wt %, or about 25 wt % PCR PS. The styrenic resin so produced may have processability and performance suitable for the production of articles of manufacture. Systems and methods for producing such resins are discussed in detail below.

I. Styrenic Resin Production Process—An Overview

In the production of styrenic resins, polymerization reactors, which polymerize monovinylarene monomers into polymers, and processing equipment (e.g., extruders), may undergo continuous or batchwise operation. FIG. **1** depicts a block diagram of an example system for producing styrenic resins (e.g., general purpose polystyrene (GPPS), high impact polystyrene (HIPS)) incorporating PCR PS. Various suppliers **12** may provide reactor feedstocks to the system **10** via railcars, pipelines, trucks, cylinders, drums, and so forth. The suppliers **12** may include off-site and/or on-site facilities, including plants, refineries, initiator plants, and the like. Examples of possible feedstocks include post-consumer recycle polystyrene (PCR PS) **14** and monovinylarene (MVA) monomers **16**. Other feeds **18** provided by the suppliers **12** may include any one, or a combination of: comonomers (such as olefins and/or conjugated dienes), diluents (such as saturated, unsaturated, and aromatic hydrocarbons), chain transfer agents, coupling agents, initiators (such as free-radical initiators or anionic initiators), impact enhancement agents, plasticizers and other additives such as colorants, release agents, antiblock agents and other processing aids, and flame retardants. In one embodiment, the feed **18** may include either a HIPS-producing feed (e.g., synthetic rubber such as polybutadiene dissolved within MVA monomer), or an actual HIPS feed (e.g., a HIPS resin that is dissolvable/suspendable in the MVA monomer).

As set forth above "post-consumer recycle polystyrene" (PCR PS) is intended to denote a styrenic resin that has been manufactured and then used by the public consumer and returned to a manufacturer or producer. Thus, "PCR PS," as used herein, refers to a styrenic resin (e.g., GPPS, HIPS), obtained as a raw or processed styrenic material that has been previously incorporated into one or more consumer products, used by the consumer, and returned to a manufacturer/producer. The PCR PS may therefore consist entirely or essentially of styrenic polymers (e.g., HIPS and/or GPPS resins) or may include styrenic polymers and other materials that affect the properties (e.g., appearance, performance, processability) of the styrenic material. As noted above, the other materials may include consumer waste, metallic objects (e.g., conductors, wire hangers), and other polymeric materials commonly associated with polystyrene in consumer products. By way of non-limiting example, such other polymeric materials may include any one or a combination of polyolefins (e.g., polyethylene, polypropylene), polyacrylates (e.g., polyacrylonitrile), polyconjugated dienes (e.g., polybutadiene), polyvinyl halides (e.g., polyvinylchloride) and the like. Other polymers and materials typically associated with styrenic polymers in consumer products will be readily apparent to those of ordinary skill in the art and are within the scope of the present disclosure. While any source of PCR PS is presently contemplated, in certain embodiments, it may be desirable to utilize a source of PCR PS that has had limited to no contact with materials that may be undesirable for subsequent food contact applications, such as beverage containers, food trays, and the like. One example source of PCR PS is NEXTLIFE RECYCLING SUSTAINABLE POLYSTYRENE® PCR PS, which is commercially available from NextLife Recycling, LLC of Boca Raton, Fla.

"Monovinylarene monomer," or "MVA monomer," as used herein, refers to an organic component containing a single carbon-carbon double bond and at least one aromatic moiety. By way of non-limiting example, the MVA monomer may include a total of 8 to 18 carbon atoms, such as 8 to 12 carbon atoms. Example monovinylarenes include, but are not limited to, alkyl-substituted styrenes such as α-alkylstyrenes (for example, α-methylstyrene and α-ethylstyrene), ring-substituted styrenes (for example, 2,4-dimethylstyrene; o-ethylstyrene, t-butyl-styrene, vinyltoluene and particularly p-vinyltoluene, ring-substituted halostyrenes such as chlorostyrene and 2,4-dichlorostyrene, styrene substituted with both a halo and alkyl group, such as 2-chloro-4-methylstyrene, vinyl anthracene, and mixtures thereof. In one embodiment, the monovinylarene is styrene.

The PCR PS **14**, MVA monomer **16**, and a portion of the feed **18** (e.g., diluent, a styrene/polybutadiene mixture) may be provided to a PCR PS feed preparation system **20** that is configured to produce a PCR PS feed **22**. The PCR PS feed **22** may include treated PCR PS in MVA monomer and may, in certain embodiments, include feed components to produce a HIPS resin, such as synthetic rubber dissolved in MVA monomer. To produce the PCR PS feed **22**, as discussed in detail below with respect to FIGS. **2-4**, the PCR PS feed preparation system **20** receives at least the PCR PS **14** and the MVA monomer **16** and conditions a mixture produced therefrom such that the PCR PS feed **22** is suitable for introduction into a feed system **24** that supplies a reactor feed **26** to a reactor system **28**. Generally, the PCR PS feed preparation system **20** may include slurry tanks, feed hoppers, dissolvers, strainers, filters (e.g., bag filters, self-cleaning filters), pumps, flow control valves, surge tanks, holding tanks, and the like in any configuration suitable for receiving the PCR PS **14** and MVA monomer **16**, producing a dissolved solution therefrom, filtering the dissolved solution to remove contaminants, and for storing the PCR PS feed **22** for eventual provision to the feed system **24** and/or the reactor system **28**.

Before use, the PCR PS **14**, MVA monomer **16**, and any components of the feed **18** that are used to produce the PCR PS feed **22** (e.g., a styrene/synthetic rubber mixture for HIPS production) may, in some embodiments, be stored in feed tanks, diluent vessels, and/or sent through treatment beds to remove certain components (e.g., oxygen, water). Furthermore, in operation, the PCR PS feed preparation system **20** may also store, treat, and meter a portion of diluent and/or unreacted monomer **30** recovered from reactor effluent **32** by an effluent treatment system **34** for recycle to the reactor system **28**. It should be noted that while the feed system **24** is illustrated as receiving the PCR PS feed **22** prior to its introduction into the reactor system **28**, in other embodiments the PCR PS feed **22** may be provided directly from the PCR PS feed preparation system **20** to the reactor system **28**.

In addition to, or in lieu of receiving the PCR PS feed **22**, the feed system **24** may also receive and prepare components of the feed **18** for introduction into the reactor system **28**. For example, an initiator may be mixed with diluent (e.g., ethylbenzene) or mineral oil in initiator preparation tanks. In embodiments where the resin produced by the system **10** incorporates a HIPS resin, the feed system **24** may also receive a feed of synthetic rubber dissolved/suspended in a monovinylarene monomer, or may separately receive the polybutadiene and monovinylarene monomer to produce such a solution. The feed system **24** may also receive in-system recycled components **36** recovered from the effluent treatment system **34** such as diluent and other unused components of the feed **18**. In total, the feed **18** and recovered reactor effluent are processed in the feed system **24** and fed as the reactor feed **26** (e.g., the PCR PS feed **22**, MVA monomer, comonomer, diluent, initiators, additives, or combinations thereof) to the reactor system **28**. Further, the feed system **24** typically provides for metering and controlling the addition rate of the reactor feed **26** into the reactor system **28** such that, along with reactor system configuration (e.g., operational parameters), desired reactor stability and/or desired styrenic resin properties or production rate are obtained/maintained.

The reactor system **28** may have one or more reactors each having one or more reaction vessels or zones. For example, the reactor system **28** may include one or more reaction vessels operating in a series configuration, parallel configuration, or any suitable configuration. By way of non-limiting example, the reactors of the reactor system **28** may be continuous stirred tank reactors (CSTR), stirred tower reactors, axially segregated horizontal reactors, pipe reactors, and the like. In the reactor vessels or zones, the MVA monomer **16** is polymerized according to a free-radical bulk or solution polymerization process. For example, as discussed in further detail below, the polymerization may be conducted in the presence of an initiator, which may be a peroxide-based or an azo-based initiator.

The polymerization process conducted within the reactor system **28** produces a product containing polymer particulates, typically referred to as polymer melt or granules. The melt may possess one or more melt, physical, rheological, and/or mechanical properties of interest, such as density, melt flow rate (MFR), extensional viscosity (EV), copolymer or comonomer content, modulus, color, clarity, and crystallinity. The reaction conditions, such as the particular materials selected for the reaction, temperature, pressure, flow rate, mechanical agitation, product takeoff, component concentrations, polymer production rate, and so forth, may be selected to achieve a desired range of properties.

The effluent **32** from the reactors within the reactor system **28** may include the polymer melt as well as non-polymer components, such as diluent, unreacted monomer/comonomer and residual additives. After leaving the reactor system **28**, the effluent **32** may be subsequently processed, such as by the effluent treatment system **34**, to separate non-polymer components such as the diluent and/or unreacted monomer **30** or other recycled components **36** from styrenic polymer melt **38**. In accordance with the present disclosure, the styrenic polymer melt **38** is generally a post-consumer containing (PCC) styrenic resin, which is a styrenic resin containing both virgin and PCR styrenic materials. To separate the melt **38** from certain other materials, the effluent treatment system **34** may include various devolatilizers, flashline heaters, flash vessels, and so on, which are configured to remove certain compounds (e.g., unreacted monomer and diluent) from the melt **38**.

The recovered non-polymer components may be processed, such as by a fractionation system within the effluent treatment system **34**, to separate unreacted monomer and/or diluent from other components not typically associated with the feed **18**. The recycled components **36** may then be returned to the reactor system **28** via the feed system **24**.

The styrenic polymer melt **38** may be further processed within a processing system **40** (e.g., an extrusion/loadout system). In the processing system **40**, in one embodiment, the styrenic polymer melt **38** is typically extruded through a die, cooled, and then pelletized to produce polymer pellets **42** with the desired mechanical, physical, and melt characteristics. In another embodiment, the styrenic polymer melt **38** is extruded into a cutting chamber, and is cooled in a water system disposed at or near the discharge of the pelletizer/cutter. Extruder feed may contain additives, such as UV inhibitors, antioxidants, colorants, processing aids, flame retardants, and so forth, which are added to the styrenic polymer melt **38** to impart desired characteristics to the extruded styrenic polymer pellets **42**. Thus, "pellet," as used herein, is intended to denote a physical form of a resin that formed by extruding, cooling, and cutting the resin.

In general, the styrenic polymer pellets **42** may then be transported to a product load-out area where the pellets may be stored, blended with other pellets, and/or loaded into railcars, trucks, bags, and so forth, for distribution to customers **44**. The customers **44** may utilize the styrenic polymer pellets **42** to form various articles **46**. For example, the styrenic polymer pellets **42** can be used to make telephones, house wares, refrigerator parts, lawn and garden tools, kitchen appliances, electronics housings, toys, window pieces, packaging articles, food packaging and food service articles, beverage containers, medical parts or devices, foam insulation, foam beverage containers, foam coolers, and the like. Indeed, any number of processes may be performed on the pellets **42** to produce the articles **46**, including foam sheet extrusion, foam board extrusion, extrusion and thermoforming, injection molding, and similar processes.

For example, forming the article **46** may include producing a foaming mixture. The foaming mixture may include at least the styrenic resin and a blowing agent, and is heated and/or subjected to a reduced pressure to release the blowing agent to produce a foamed styrenic resin. The foamed styrenic resin may be subsequently extruded into a sheet and thermoformed to produce the article **46**, or may be extruded into a board (typically thicker than a sheet) and used as foam insulation or the like. Another process may include expanding the pellets **42** (e.g., with air, steam, or another gas) and molding the resulting expanded resin to produce the article **46**.

In still other processes, the pellets **42** may be extruded to produce a film or sheet. The extruded film or sheet may be blown or cast to produce a blown or cast film, which may then be rolled or thermoformed to produce a shaped article. The shaped article, in some embodiments may be trimmed to produce the article **46**. In certain embodiments, the PCC styrenic resin may have properties so as to enable the trimmings from such a process to be re-ground, re-extruded, and subsequently incorporated into an article. In still other embodiments, a polymer melt may be produced from the pellets **42**, and the melt may be injection molded to produce the article **46**.

As noted above, the PCR PS feed preparation system **20** is configured to produce the PCR PS feed **22** in a manner suitable for subsequent polymerization and production of the PCC styrenic resin pellets and resulting products discussed above. In other words, the PCR PS feed **22** may be produced in such a way so as to enable its use within the reactor system **28**. Accordingly, the PCR PS feed **22** provided to the feed system **24** and/or the reactor system **28** may be substantially free of components that would otherwise deleteriously affect the free-radical polymerization process and properties of the resulting product. For example, the PCR PS feed **22** may be substantially free of oxygen, metallic components, consumer waste, non-styrenic resins, and the like. The PCR PS feed preparation system **20** includes a number of subsystems discussed below with respect to FIGS. **2**-**4** that enable the production of the PCR PS feed **22** in this manner.

II. Preparation of the Post-Consumer Recycle Polystyrene Feed

One subsystem of the PCR PS feed preparation system **20**, which is diagrammatically depicted in FIG. **2**, is a receiving system **60**. The receiving system **60** is configured to receive the PCR PS **14** (e.g., from one of the suppliers **12**) and to prepare a pneumatically transported stream of PCR PS **62** for further treatment in the PCR PS feed preparation system **20**. The receiving system **60** includes a feed hopper **64** configured to collect the PCR PS **14** from one or more sources (e.g., a transport vehicle **66**, a silo **68**) and to introduce the PCR PS **14** into flow path **70** of the PCR PS feed preparation system **20**. The feed hopper **64** is generally configured to receive the PCR PS **14** in any form, such as flake or pellets, or a mixture thereof. In certain embodiments, it may be desirable for the PCR PS **14** to be in flake form for ease of conveyance, better dissolution rates, and more efficient filtration, as discussed with respect to FIGS. **2**-**4** below. "Flake," as used herein, is intended to denote a physical form of a resin produced by mechanically grinding the resin. Thus, in accordance with the present disclosure, flakes may include chips, granules, and other similar forms of a resin.

In the illustrated embodiment, the feed hopper **64** is fluidly coupled to or includes a first cyclone separator **72** and a vacuum blower **74**. As the vacuum blower **74** pulls an exhaust flow (e.g., air, dust, debris) from the feed hopper **64**, the first cyclone separator **72** removes particulates (e.g., dust, debris) from the exhaust flow and enables the air in the exhaust to be vented into the atmosphere. The cyclone separator **72** may also prevent PCR PS particulates from reaching the vacuum blower **74**. The vacuum blower **74** and/or first cyclone separator **72** may be operated in a continuous or intermittent fashion until the feed hopper **64** is filled with a desired amount of PCR PS **14**.

During operation, the PCR PS **14** collects and fills the feed hopper **64** from a bottom region **78** to a top region **80**. While the top region **80** is generally coupled to the vacuum blower **74** and the first cyclone separator **72**, the bottom region **78** is coupled to a first rotary valve **82** to enable the PCR PS **14** to controllably exit the feed hopper **64**. In some embodiments, there may be one, two, three, four or more rotary valves operating independently or substantially in unison.

A meter **84** may be disposed along the flow path **70** for monitoring and/or metering the amount of PCR PS **14** that has been provided into the flow path **70**. For example, the meter **84** may be a rotary weigh meter, a pressure meter, a flow meter, or any other meter suitable for measuring or providing feedback indicative of the amount of PCR PS **14** provided into the flow path **70**. In certain embodiments, the measurements or feedback may be used as input for adjustments to the first rotary valve **82**. For example, the measurements and/or feedback may be provided to a controller communicatively coupled to the meter **84**, such as a distributed control system (DCS) **86** configured to control operational parameters of at least some elements of the PCR PS feed preparation system **20**.

In certain embodiments, the meter **84** (e.g., a weigh meter) may collect a predetermined amount of PCR PS **14** (e.g., a predetermined weight) such that a controlled amount of PCR PS **14** is provided to downstream equipment of the PCR PS feed preparation system **20**. A second rotary valve **88** may also be disposed along the flow path **70** downstream of the meter **84**. The second rotary valve **88** may control (e.g., via control signals provided from the DCS **86**) a flow of the PCR PS **14** from the meter **84** and to a pickup tee **90**. At the pickup tee **90**, the PCR PS **14** is subjected to a flow of a conveyance gas **92** for provision to a dissolver system **94** of the PCR PS feed preparation system **20**.

The conveyance gas **92** may be generated using any gaseous source (e.g., air, helium, argon, nitrogen), though it may be desirable for the conveyance gas **92** to be generated using air **96** collected from the atmosphere for cost considerations. A pressure blower **98** collects the air **96** and pressurizes it. An air cooler **100** is disposed downstream from the pressure blower **98** and upstream of the pickup tee **90**. The air cooler **100** includes an impeller **102**, which may be driven by a motor **104** communicatively coupled to the DCS **86**. The DCS **86** is therefore capable of at least partially controlling the flow and temperature of the conveyance gas **92**.

The DCS **86** may control the timing and other operational parameters of these and other elements of the PCR PS feed preparation system **20**. Generally, the DCS **86** may be any processor-based device capable of performing control routines to adjust operational parameters as a result of feedback obtained from any one or a combination of elements within the entire system **10**, such as the PCR PS feed preparation system **20**. For example, the DCS **86** may include one or more processors configured to perform instructions stored on a tangible, machine-readable medium, the stored instructions resulting in the performance of the control routines. For example, as illustrated, the DCS **86** may be communicatively coupled to, and may control the operation of, any one or a combination of the vacuum blower **74**, the first cyclone separator **72**, the first and second rotary valves **82**, **88**, the meter **84**, the pressure blower **98**, and the conveying blower **100**. The DCS **86** may obtain feedback indicative of the fill level in the feed hopper **64**, flow rates of the conveyance gas **92**, amount of PCR PS **14** measured at the meter **84**, or any other such parameter, at least using a series of transducers **106**, **108**, **110**, the meter **84**, or any combination thereof. The transducers **106**, **108**, **110** may monitor/measure temperature, pressure, flow rates (e.g., mass flow rates), or any combination thereof.

As a result of such measurements, the DCS **86** may adjust, when appropriate, one or more operational parameters of the receiving system **60**. By way of non-limiting example, the DCS **86** may open the feed hopper **64** to the flow path **70** via the first rotary valve **82** once a desired amount of PCR PS **14** has been provided to the feed hopper **64**. Conversely, the DCS **86** may close the feed hopper **64** to the flow path **70** via the first rotary valve **82** once a desired amount of PCR PS **14** has been provided to the flow path **70** as measured by the meter **84**. The opening and closing of the flow path **70** between the pickup tee **90** and the meter **84** via the second rotary valve **88** may also be controlled based at least in part on similar feedback. Additionally or alternatively, the DCS **86** may control the flow rate of the stream of PCR PS **62** as it is conveyed to the dissolver system **94**.

It should be noted that while the DCS **86** is described below as performing adjustments to certain operational parameters, the DCS **86** may operate in conjunction with, or in lieu of, an operator. Further, any one or a combination of the control acts described herein may be performed by an operator in lieu of the DCS **86**. For example, an operator may make adjustments to valve positions, power provided to certain components, and other control parameters, as a result of indications obtained from the PCR PS feed preparation system **20**. By way of non-limiting example, such user-perceivable indications may include gauges, lights, readouts, displays, alarms, and so on, for providing auditory, visual, and/or tactile feedback that a change in an operational parameter may be appropriate. Accordingly, with respect to the operation of the receiving system, the DCS **86**, in addition to or in lieu of an operator, may control, adjust, and/or monitor a flow of the stream of PCR PS **62** to the dissolver system **94**.

Moving now to FIG. **3**, the illustrated dissolver system **94** includes a first dissolver **120** and a second dissolver **122** for dissolving the PCR PS **14** in the MVA monomer **16** to produce a dissolved mixture **124**. As noted above, it may be desirable for the PCR PS **14** to be in flake (e.g., granules, chips) form rather than other forms such as pellets, as it is now recognized that flakes may provide enhanced dissolution rates within the dissolvers. As illustrated, the first and second dissolvers **120**, **122** may be configured to operate such that as one dissolver is providing the dissolved mixture **124** downstream, the other dissolver is preparing a fresh batch of the dissolved mixture **124**. In this way, the dissolver system **94** may substantially continuously produce the dissolved mixture **124**.

In other embodiments, one of the first or second dissolvers **120**, **122** may not operate while the other is operational, such that the dissolver that is not operating may serve as a backup should any undesirable operational condition be detected in the operating dissolver. Further, the dissolver system **94** may include one or more than two (e.g., three, four, five, or more) dissolvers depending on the desired throughput of the dissolver system **94**, spatial constraints, vessel sizes, equipment limitations, and so forth.

The stream of PCR PS **62**, as noted above, includes at least the PCR PS **62** and the conveyance gas **92**, and flows along the flow path **70** generally toward the first and second dissolvers **120**, **122**. In particular, as illustrated, the stream of PCR PS **62** flows along the flow path **70** and is split into a first intermediate flow path **126** toward the first dissolver **120** or a second intermediate flow path **128** toward the second dissolver **122** as determined by a diverter valve **130** having an actuator **132** communicatively coupled to the DCS **86**. Thus, the stream of PCR PS **62** may be provided to either of the dissolvers **120**, **122**.

A number of features may be disposed along the first and second intermediate flow paths **126**, **128** to feed the dissolvers **120**, **122**. For example, elements configured to remove certain types of contaminants (e.g., metals, dust, particulates) from the stream of PCR PS may be disposed along either flow paths **126**, **128** including features for removing all or a portion of the conveyance gas **92** from the stream of PCR PS **62**. For example, such features may be desirable to remove materials that may deleteriously affect the free-radical polymerization process, generate color bodies, or cause an undesirable condition in the dissolvers **120**, **122**.

As illustrated, the first and second intermediate flow paths **126**, **128** include second and third cyclone separators **134**, **136**, respectively, which are each configured to aid in the removal of dust and particulates from the stream of PCR PS **62**. A rotary valve **138** disposed at an exit of the second cyclone separator **134** and/or a rotary valve **140** disposed at an exit of the third cyclone separator **136** are actuated (e.g., by the DCS **86**) to provide the PCR PS to the dissolvers **120**, **122**.

In certain embodiments, for example, the amount of PCR PS **14** collected within each of the second and third cyclone separators **134**, **136** may be monitored using transducers **142**, **144** disposed on and/or within each cyclone separator. Additionally or alternatively, the DCS **86** may monitor the amount of PCR PS **14** flowing along the first and second intermediate flow paths **126**, **128** using transducers **146**, **148** disposed downstream from the second and third cyclone separators **134**, **136**. The DCS **86** may make adjustments to the respective positions of rotary valves **138**, **140** in order to affect the amount of PCR PS **14** provided to the first and/or second dissolvers **120**, **122** as a result of such monitoring.

It should be noted that the dissolution of PCR PS **14** in the MVA monomer **16** may not necessarily be instantaneous. In addition, agglomeration of the PCR PS **14** may form a mass that may be difficult to dissolve. Agglomerated polymer masses can cause a variety of undesirable operating conditions such as plugged lines, and may damage agitators, pumps, or the like. Thus, the PCR PS **14** may be controllably provided to the dissolvers **120**, **122** after a predetermined amount of MVA monomer **16** is in the dissolvers **120**, **122**, and in a manner that mitigates agglomeration of the PCR PS **14**. Therefore, the DCS **86**, an operator, or both, may monitor and/or control the flow of the PCR PS **14** into the dissolvers **120**, **122** based at least on the amount of MVA monomer **16** in the dissolvers **120**, **122** using the rotary valves **138**, **140** and/or stop valves **154**, **156**. The stop valves **154**, **156** enable a flow of PCR PS **14** to the first and/or second dissolvers **120**, **122** to be stopped as desired. For example, the first and/or second stop valves **154**, **156** may be closed during a time period in which the PCR PS is dissolving within the MVA monomer **16** (i.e., a dissolving period). After the dissolving period is over, after the resulting mixture is discharged from the first and/or second dissolvers **120**, **122**, and after a desired amount of MVA monomer **16** has been provided to the dissolvers **120**, **122**, the first and/or second stop valves **154**, **156** may be re-opened to allow fresh PCR PS **14** to be charged (i.e., added) into the first and/or second dissolvers **120**, **122**.

The first and second flow paths **126**, **128** may also include a first magnetic separator **150** and a second magnetic separator **152** for removing metallic objects from the PCR PS **14**. However, it is presently contemplated that magnetic separators may be disposed anywhere in the PCR feed preparation system **20**, such as between the meter **84** and valve **88** of FIG. **2**. Such removal may be desirable due at least in part to the sensitivity of the polymerization reaction to metallic species, which can consume the initiator, can terminate active polymer chains (resulting in decreased molecular weights), and can also, in some situations, change polymerization rates and/or the nature of the polymers formed (e.g. branching). While any magnetic separator may be used in accordance with present embodiments, in certain configurations, the first and second magnetic separators **150**, **152** may operate by allowing the PCR PS **14** to generally flow through a hollow region defined by one or more magnetically charged walls. Magnetic or magnetizable objects (e.g., particulates) may collect on the walls while non-magnetic objects may pass through the hollow regions of the first and second magnetic separators **150**, **152**. In certain embodiments, the first and second magnetic separators **150**, **152** may, alternatively or additionally, be electrostatically charged so as to collect dust and other such small contaminants.

As noted above, MVA monomer **16** is provided, in addition to the PCR PS **14**, to the first and second dissolvers **120**, **122** to generate the dissolved mixture **124**. While any addition sequence is presently contemplated, it may be desirable to provide the MVA monomer **16** to the dissolvers **120**, **122** before charging the PCR PS **14**. In particular, it may be desirable to first have a predetermined level of MVA monomer **16** in the dissolvers **120**, **122** before charging the PCR PS **14** to facilitate dissolution. The MVA monomer **16** may be provided from a source such as a storage vessel, a tank, a pipeline, or the like, along first and second monomer flow paths **160**, **162** to the first and second dissolvers **120**, **122**, respectively. In certain embodiments, the MVA monomer **16** may be treated to remove materials that can negatively impact the free-radical polymerization process carried out in the reactor system **28**, the properties of the PCC styrenic resin produced by the system **10**, or both.

As may be appreciated, the first and second monomer flow paths **160**, **162** may have various pumps, blowers, valves, and so forth, which are configured to motivate and control a flow of the MVA monomer **16** toward the dissolvers. Generally, one or more flow control and/or stop valves may generally be configured to start, stop, or adjust the flow of the MVA monomer **16** along the first and second monomer flow paths **160**, **162** so as to provide a desired amount of MVA monomer **16**, at a desired rate and in desired amounts, to the first and second dissolvers **120**, **122**. In addition, one or more transducers (e.g. flow meters) may be positioned between the source of the MVA monomer **16** and the dissolvers **120**, **122** for monitoring the flow of the MVA monomer **16**.

The desired amount of MVA monomer **16** provided to the first and second dissolvers **120**, **122** may be determined based at least partially on the desired concentration of PCR PS **14** within the MVA monomer **16**, the capacity of the first and second dissolvers **120**, **122**, equipment limitations (e.g. agitators, pumps), and similar considerations. The rate at which the MVA monomer **16** is provided to the first and second dissolvers **120**, **122** may also be determined based at least partially on these considerations. By way of example, the PCR PS **14** and the MVA monomer **16** may be provided to the first and second dissolvers **120**, **122** in respective amounts such that the dissolved mixture **124** contains between approximately 5 and 50 weight percent PCR PS in MVA monomer, such as between approximately 15 and 35 weight percent, between approximately 20 and 30 weight percent, or approximately 25 weight percent.

To facilitate mixing and dissolution, the first and second dissolvers **120**, **122** also include first and second agitators **176**, **178**, which are generally configured to agitate the mixture produced when the PCR PS **14** and the MVA monomer **16** are provided to the first and second dissolvers **120**, **122**. For example, during operation, the agitators **176**, **178** may agitate the MVA monomer **16** as the PCR PS **14** is charged into the dissolvers **120**, **122** to facilitate dissolution.

As illustrated, the first and second agitators **176**, **178** include first and second motors **180**, **182**, respectively, which are coupled to first and second impellers **184**, **186** disposed within an interior of the first and second dissolvers **120**, **122**. The DCS **86** may control either or both of the first and second motors **180**, **182** to stop, start, or otherwise adjust the speed of the impellers **184**, **186**. In doing so, the agitation rate can be adjusted to ensure a desired agitation rate between the PCR PS **14** and the MVA monomer **16** to facilitate dissolution.

The dissolver system **94** also utilizes inert gas **190** to prevent undesirable operating conditions within the dissolvers **120**, **122**. The inert gas **190** may be delivered from a vessel such as a tank or canister, or from an air separation unit that produces a stream of nitrogen from atmospheric air. By way of non-limiting example, the inert gas **190** may be nitrogen, helium, argon, or the like. The flow of the inert gas **190** into the dissolvers **120**, **122** may be controlled automatically by the DCS **86** and/or by an operator.

After an amount of time, the dissolved mixture **124** is produced from the PCR PS **14** and the MVA monomer **16** within the first and second dissolvers **120**, **122**. Indeed, after the dissolved mixture **124** is produced, it is discharged from the first and second dissolvers **120**, **122** and into the flow path **70**, which leads from the dissolver system **94** to a filter system **200** of the PCR PS feed preparation system **20**. As discussed in detail below, the flow of the dissolved mixture **124** to the filter system **200** may be controlled using variable displacement pumps disposed downstream of the dissolvers **120**, **122**. However, the use of other control features, such as flow control valves, is also presently contemplated.

In accordance with present embodiments, the filter system **200** generally includes features for filtering the dissolved mixture **124** in a controlled manner that enables the removal of a substantial portion of non-styrenic materials (e.g., undissolved non-styrenic polymers and/or particulates) from the dissolved mixture **124**. As noted above, increased filtration efficiency may be obtained when using the PCR PS **14** in flake or chip form as opposed to pellet form, though either form may be used in accordance with present embodiments. Indeed, the removal of such materials may enable a PCC styrenic resin produced from a mixture incorporating the PCR PS **14** to have improved properties (e.g., performance, processability, appearance) compared to a PCC styrenic resin produced from a mixture that is prepared using techniques that do not include the preparation techniques discussed herein (e.g., compounding).

The embodiment of the filter system **200** illustrated in FIG. **4** includes the flow path **70**, which, in the filter system **200**, is configured to flow the dissolved mixture **124** through various features configured to prepare the mixture for provision to the reactor system **28**. In particular, the dissolved mixture **124** may be received into the filter system **200** of the PCR PS feed preparation system **20** along the flow path **70**, which splits into third and fourth intermediate paths **220**, **222**. The third and fourth intermediate paths **220**, **222** lead to first and second filter feed pumps **224**, **226**, which may be variable displacement pumps and which are on-line spares for one another. The flow rate of the dissolved mixture can be controlled (e.g., by an operator and/or the DCS **86**) using the pumps **224**, **226** such that appropriate flow rates for the dissolved mixture **124** provided to the first and second filters **228**, **230** are obtained. Such flow rates may depend on the specifications of the filters, the capability of the filter feed pumps **224**, **226**, the length of conduits fluidly coupling the pumps **224**, **226** to the filters **228**, **230**, or any combination thereof.

As illustrated, the third and fourth intermediate flow paths **220**, **222** may re-converge into the flow path **70**, and may diverge into fifth and sixth intermediate flow paths **232**, **234**, which lead to the first filter **228** and the second filter **230**, respectively. However, it should be noted that in other embodiments, the third and fourth intermediate flow paths **220**, **222** may not re-converge and, instead, may lead directly to the first and second filters **228**, **230**. First and second filter feed flow control valves **236**, **238** may be disposed along the fifth and sixth intermediate flow paths **232**, **234**, respectively, to determine which of the first filter **228** or the second filter **230** will receive the flow of the dissolved mixture **124**. In one embodiment, the DCS **86** may control the operation of the valves **236**, **238**.

The first and second filters **228**, **230** include any filter suitable for removing targeted non-styrenic undissolved materials (e.g., non-GPPS and/or non-HIPS materials) from the dissolved mixture **124**. For example, the first and second filters **228**, **230** may include filter screens generally having a mesh size of between approximately 1 micron and 1 millimeter, such as between approximately 10 microns and 400 microns, for removing undissolved materials. In the illustrated embodiment, the first and second filters **228**, **230** are self-cleaning filters having cylindrical screen meshes **244**, **246**, and augers **248**, **250** disposed within the cylindrical screen meshes **244**, **246**, the augers **248**, **250** being coupled to motors **252**, **254**. By way of non-limiting example, the first and second filters **228**, **230** may be self-cleaning Eco Filters available from Russell Finex, Inc. of Pineville, N.C. As illustrated, in certain embodiments, the DCS **86** may control the operation of the motors **252**, **254**.

As depicted, the dissolved mixture **124** is provided internal to the cylindrical screen meshes **244**, **246**. All dissolved components of the dissolved mixture **124** pass through the cylindrical screen meshes **244**, **246** while some or all of the undissolved materials do not. Instead, the undissolved particulates (e.g., undissolved resins) are carried by the augers **248**, **250** to discharge lines **256**, **258**. In addition, the cylindrical screen meshes **228**, **230** may be cleaned by the action of the augers **248**, **250**. A series of discharge valves **260**, **264**, **266**, **268** may be disposed along the discharge lines **256**, **258** to control the rate at which undissolved materials are discharged from the first and second filters **228**, **230**. First and second waste vessels **270**, **272** may also be provided for collecting the undissolved non-styrenic materials for later treatment and disposal. While illustrated as including two waste vessels, it should be noted that, in certain embodiments, discharge lines **256**, **258** may converge such that there is only one waste vessel.

As set forth above, the illustrated first and second filters **228**, **230** include cylindrical screen meshes **244**, **246**. In a general sense, the cylindrical screen meshes **244**, **246** are sized so as to remove undissolved solids (e.g., undissolved non-styrenic resins) while enabling a sufficient flow of the dissolved mixture **124** therethrough. Additionally, the sizes of the meshes **244**, **246** may be the same or different. By way of non-limiting example, the cylindrical screen meshes **244**, **246** have screen sizes between approximately 5 and 900 microns, such as between approximately 40 and 400 microns, between approximately 60 and 100 microns, or approximately 60 microns. While such sizes may be appropriate for the removal of most non-styrenic materials, trace amounts of other materials, such as finer particulates, may remain. Accordingly, as discussed in detail below, the filter system **200** may also include at least one additional filter, such as a bag filter **276** for removing additional undissolved particulates.

The first and second filters **228**, **230**, as illustrated, output the undissolved materials via discharge lines **256**, **258**, and also output a filtered mixture **278** via respective exit paths **280**, **282**. At this point, in certain embodiments, the filtered mixture **278** may be at least 95 weight percent styrenic materials (including polymer and monomer), with a significant portion of the non-styrenic materials being removed by cyclonic separation in the receiving system **60** (FIG. **2**) and/or the first and second filters **228**, **230**. Indeed, the filtered mixture **278** may be between approximately 97 weight percent and 100 weight percent styrenic materials, such as between approximately 98 weight percent and 100 weight percent styrenic materials. The exit paths **280**, **282** may include respective flow control valves **284**, **286** for adjusting a flow of the filtered mixture **278** through the paths **280**, **282**. As illustrated, the DCS **86** may be communicatively coupled to the valves **284**, **286** such that the flow control may be performed automatically.

The exit paths **280**, **282** may re-converge into the flow path **70**, which directs the filtered mixture **278** toward a surge tank **288** for storing the filtered mixture **278**. First and second reactor feed pumps **292**, **294**, which may be variable displacement pumps, are disposed downstream of the surge tank **288** for motivating the filtered mixture **278** and the PCR PS feed **22** to the reactor system **28**. As illustrated, the reactor feed pumps **292**, **294** are on-line backups for one another, and may be controlled by the DCS **86** and/or an operator.

As noted above, the filtered mixture **278** may be filtered downstream of the surge tank **288** by one or more bag or cartridge filters **276** to generate the PCR PS feed **22**. Thus, the filtered mixture **278** may be motivated along the flow path **70** by the reactor feed pumps **292**, **294**, and to the bag or cartridge filter **276**. By way of non-limiting example, the bag or cartridge filter **276** may include one or more filter screens or meshes each having a screen or mesh size between approximately 1 micron and 800 microns, such as between approximately 10 and 200 microns. Such a screen or mesh size may be desirable to remove any remaining dust or particulates from the PCR PS feed **22** before provision to the reactor system **28**.

In certain embodiments, other components of the feed **18** (FIG. **1**), such as additional diluent, additional monomer, comonomers, HIPS feed, HIPS-producing feed, or the like, may be combined with the filtered mixture **278** downstream of the reactor feed pumps **292**, **294** to generate the PCR PS feed **22**. Therefore, in certain embodiments, the PCR PS feed **22** may consist essentially of PCR PS in MVA monomer, while in other embodiments the PCR PS feed **22** may include the PCR PS in MVA monomer in addition to diluents and/or other additives that affect the polymerization reaction performed within the reactor system **28** and/or the resulting PCC styrenic resin produced by the reactor system **28**. As noted above, other in-system recycled materials **36** (FIG. **1**) may be combined with the filtered mixture **278** from the effluent treatment system **34** (FIG. **1**).

As discussed above with respect to FIG. **1**, the PCR PS feed **22** may be provided either directly to the reactor system **28** or indirectly to the reactor system **28** via the feed system **24**. In the embodiment illustrated in FIG. **4**, the PCR PS feed **22** is provided directly to the reactor system **28**, though in other embodiments the configuration in FIG. **4** may be used in conjunction with the feed system **24**. Further, in certain embodiments, the feed system **24** may simply include a series of injection ports or other similar features disposed directly on a reactor of the reactor system **28** for introducing the reactor feed **26**. Thus, in certain embodiments, a stream containing a synthetic rubber, such as polybutadiene, dissolved in MVA monomer may be provided directly to the reactor system **28**.

III. Preparation of the Post-Consumer Recycle (PCR) Styrenic Resin

As set forth above, in addition to providing systems and methods for producing a high quality reactor feed including post-consumer (PC) polystyrene, the present disclosure also provides embodiments for producing a styrenic resin incorporating the PCR PS in a manner that enables the resin (a post-consumer recycle (PCR) resin) to have properties (e.g., performance, processability, appearance) suitable for use in the production of articles of manufacture. For example, it is now recognized that the production of a virgin styrenic resin in the presence of the PCR PS **14** enables the production of a substantially homogeneous PCC styrenic resin melt stream with improved chain length and enhanced chain entanglement between the PCR PS **14** and the virgin styrenic resin produced in-reactor. Thus, the properties of the virgin styrenic resin are better able to offset certain of the undesirable properties of the PCR PS **14** when compared to other incorporation methods, such as compounding. As discussed in detail below, such in-reactor produced resins may have better appearance, processability, and performance when compared to a resin produced by compounding the virgin material and the PCR PS **14**. Indeed, it is also now recognized that the filtration of the PCR PS **14** discussed above produces a higher quality feed for the reactor system **28**, which enables reduced heat history leading to improved chain entanglement, appearance, etc., that would otherwise not necessarily be obtained. For example, removal of non-styrenic components from the PCR PS **14**, such as polypropylene, polyvinylchloride, and the like, reduces cosmetic imperfections and defects in appearance. The consistency of the PCC styrenic resin and its properties may also be improved.

Further, it should be noted that the use of self-cleaning filters as either or both of the first and second filters **228**, **230** may be particularly advantageous. For example, in accordance with present embodiments, it has been found that self-cleaning filters as the first and/or second filters **228**, **230** enable the system **10** to produce a higher-quality PCC styrenic resin compared to other configurations in which such filters are not used. While not wishing to be bound by theory, it is believed that the use of self-cleaning filters as either or both of the first and second filters **228**, **230** may enable continuous operation of the reactor system **28** by providing a substantially continuous feed of the PCR PS feed **22**. In providing the substantially continuous feed of the PCR PS feed **22**, the reactor system **28** may enter into a steady state of operation after the reactor system **28** has been continuously operating for a predetermined amount of time (e.g., at least approximately 5 hours, such as between approximately 5 hours and 24 hours). In the steady state of operation, variability in the operation of the components of the reactor system **28** may be reduced, which is believed to produce PCC styrenic resins having better physical properties (e.g., extensional viscosity, MFR) compared to when the reactor system **28** is not allowed to reach a steady state. Indeed, it has been found that when filters other than self-cleaning filters are utilized, variation in the operation of the reactor system **28** occurs due to downtime of the filter system **200** resulting from repeated removal and replacement of filters (e.g., bag filters, screens, and the like). This, in turn, results in a reduction of the quality of the PCC styrenic resin (e.g., in the physical properties of the resin) as well as the reproducibility of the PCC styrenic resin. Furthermore, throughput and efficiency may be reduced as well. The self-cleaning filters therefore not only enable a substantially continuous operation of the reactor system **28** for an extended period of time (e.g. at least 1 day, such as between 1 day and 1 month, between 1 day and 1 week), but the self-cleaning filters also enable the production of PCC styrenic resins having improved properties.

In view of the foregoing, it should also be appreciated that the properties of the virgin styrenic resin produced within the reactor system **28** may significantly impact the overall properties of the PCC styrenic resin. For example, in a general sense, in accordance with present embodiments, producing a virgin resin having a higher molecular weight (as measured by weight-average molecular weight (Mw) and/or number-average molecular weight (Mn)), a greater number of relatively high molecular weight chains (as reflected by Z-average molecular weight (Mz) and/or Z+1-average molecular weight (Mz+1), a lower melt flow rate (MFR), or any combination thereof, may offset the relatively poor processability and/or performance of the PCR PS **14**. Similarly, a relatively clear and colorless virgin styrenic resin (as measured by tristimulus values, haze, clarity) will offset, at least to some degree, the relatively yellowish and hazy appearance commonly associated with PCR PS.

One embodiment of the reactor system **28** that is configured to polymerize the MVA monomer **16** to produce the virgin styrenic resin in the presence of the PCR PS **14** is depicted schematically in FIG. **5**. As noted above, generally, the reactor system **28** may include any number and type of reactors and zones capable of subjecting the MVA monomer **16** to polymerization conditions. The one or more reactors of the reactor system **28** may be disposed in parallel, in series, or any combination thereof. Further, the reactor system **28** may include one or more different types of reactors capable of independently subjecting the MVA monomer **16** to particular polymerization conditions. The reactors may transfer heat, perform axial and horizontal mixing, and so on, in the same or a different manner depending on the type of reactor and the desired properties of the virgin styrenic resin produced therein. By way of non-limiting example, the reactor system **28** may include one or more tower reactors, stirred tank reactors (including recirculated loop reactors and continuously stirred tank reactors), stratified reactors, axially segregated agitated reactors, or any combination thereof. Other types of polymerization reactors suitable for the production of a styrenic resin will be readily apparent to those of skill in the art and are within the scope of the present disclosure.

In the embodiment illustrated in FIG. **5**, the reactor system **28** includes a plurality of vessels or zones, including an initial vessel or zone **300**, which receives the PCR PS feed **22** and other feed **18**, including diluents, plasticizers, initiator, chain transfer agents, and so on. The reactor system **28** also includes intermediate vessels or zones **302**, and a final vessel or zone **304**, which outputs the reactor effluent **32**. It should be appreciated, however, that any number of reaction vessels (e.g., 1, 2, 3, or more) having any number of zones (e.g., 1, 2, 3, or more) may be suitable. Thus, in certain embodiments, the reactor system **28** may include one reactor having one reaction zone, such as in embodiments where the reactor is a continuous stirred tank reactor. As noted above, the vessels or zones may be separate reactor vessels (e.g., a series of stirred tanks), or may simply be zones within a particular type of reactor. Further, while reaction mixtures **306**, **308** are illustrated as being transferred from the initial vessel or zone **300** to intermediate vessels or zones **302** and from the intermediate vessels or zones **302** to the final vessel or zone **304** in a horizontal direction, it should be noted that such a transfer may actually be occurring in a vertical direction, such as in embodiments where the vessels or zones **300**, **302**, **304** are a part of a stratified reactor or an agitated tower. Indeed, in such embodiments, the reactor may be a single vessel containing the vessels or zones **300**, **302**, **304**. Further, it should be noted that the vessels or zones **300**, **302**, **304** are illustrated as separate entities to facilitate discussion, and that in such embodiments, the vessels or zones **300**, **302**, **304** may not be segregated by walls or any other physical protrusion but, rather, may be segregated based on reactor parameters set for a particular zone or area of the reactor.

In addition to the PCR PS feed **22** and the other feed **18** provided to the initial vessel or zone **300**, certain feed components may be directly injected into any one or a combination of the vessels or zones **300**, **302**, **304** via respective injection ports **310**, **312**, **314**. For example, diluent and/or initiators, as well as HIPS-producing feed and/or HIPS feed may be directly injected into the vessels or zones **300**, **302**, **304** via their respective injection ports **310**, **312**, **314**. Further, the different injection ports **310**, **312**, **314** may not necessarily receive the same feed. In other words, while certain of the injection ports **310**, **312**, **314**, such as the injection port **310** of the initial vessel **300** and the injection port(s) **312** of the intermediate vessels or zones **302**, may receive diluent and/or initiator, the injection port **314** of the final vessel or zone **304** may receive other additives that may otherwise interfere with the polymerization process, such as antioxidants, colorants, or the like. The injection ports may be introduced throughout the process from pre-reactor vessel through solvent removal/recovery. In certain embodiments, any one or a combination of the vessels or zones **300**, **302**, **304** may produce and/or receive recycle feed (e.g., unreacted MVA monomer **16**, diluent/solvent) either from the effluent treatment system **34** or from other vessels or zones.

The reaction parameters within each of the vessels or zones **300**, **302**, **304** may also be separately and independently controlled. For example, each of the vessels or zones **300**, **302**, **304** may include various features for providing or removing heat from the polymerization reaction contents contained therein, for agitating the contents, for motivating (e.g., pumping) the contents, or any combination thereof. Heating/cooling may be accomplished using heating/cooling jackets, resistive heating elements, heat transfer tubes configured to flow heating/cooling liquids, and the like. Agitation may be accomplished using pumps, impellers, agitator blades, and the like. Indeed, each of the vessels or zones **300**, **302**, **304** may be independently heated/cooled, agitated, and motivated.

The reaction parameters can be controlled and monitored as desired (e.g. by the DCS **86** or an operator). By way of non-limiting example, control set points include feed rates, feed times, agitation rates and times, heating/cooling rates and times, transfer times (e.g. between the vessels or zones **300**, **302**, **304**), or any combination thereof. As generally noted above with respect to FIG. **1**, the reaction parameters may be selected so as to obtain desired melt, physical, rheological, and/or mechanical properties of interest, such as melt flow rate (MFR), molecular weight (e.g. Mn, Mw, Mz, Mz+1), copolymer or comonomer content, tensile strength and modulus.

In accordance with present embodiments, the vessels or zones **300**, **302**, **304** polymerize the MVA monomer **16** according to a free-radical bulk or solution polymerization process in an atmosphere that is substantially free of oxygen. Such processes utilize a reaction mixture including at least the MVA monomer **16** and can include a free-radical peroxide and/or azo-based initiator. In certain embodiments, multi-functional initiators may be desirable for producing higher molecular weight styrenic resins. Suitable peroxide initiators include benzoyl peroxide, t-butyl 2-methylperbenzoate, di-t-butyl peroxide, di(2-ethylhexyl) peroxydicarbonate, t-amyl peroctoate, t-butyl peroxybenzoate, t-butyl peroxyacetate, t-butyl peroxyoctoate, dibenzoyl peroxide, dilauroyl peroxide, 1,1-bis(t-butylperoxy)cyclohexane, 1-3-bis t-butylperoxy-(3,3,5-trimethyl cyclohexane), di-cumyl peroxide, polyesther poly-t-butylperoxycarbonate, di-t-butyl diperoxyazelate, and the like. Suitable azo initiators include 2,2'-azobis(isobutyronitrile) (AIBN), 2,2'-azobis(2,4-dimethylvaleronitrile), 1,1'-azobis(cyclohexanebarbonitrile), and the like. Photochemical initiation techniques can be employed if desired.

The initiators may be employed in a range of concentrations dependent on a variety of factors including the specific initiators employed, the desired levels of polymerization and the conditions at which the mass polymerization is conducted. Specifically, initiators may be employed in amounts from 0 to 2000, preferably from 100 to 1500, parts by weight per million parts by weight of the MVA monomer **16**.

In addition, the process may utilize a hydrocarbon solvent (e.g., if the polymerization is a solution free-radical polymerization). Acceptable solvents include normally liquid organic materials which form a solution with the MVA monomer **16** and the styrenic polymer prepared therefrom. Representative solvents include aromatic and substituted aromatic hydrocarbons such as benzene, ethylbenzene, toluene, xylene or the like; substituted or unsubstituted, straight or branched chain saturated aliphatics of 5 or more carbon atoms, such as heptane, hexane, octane or the like; alicyclic or substituted alicyclic hydrocarbons having 5 or 6 carbon atoms, such as cyclohexane; and the like. Particularly suitable solvents include substituted aromatics, with ethylbenzene, toluene, and xylene being most preferred. In general, the solvent is employed in amounts sufficient to improve the processability and heat transfer during polymerization. Such amounts will vary depending on the MVA monomer **16** and solvent employed, the process equipment and the desired degree of polymerization. If employed, the solvent is generally employed in an amount of up to about 35 weight percent, preferably from about 2 to about 25 weight percent, based on the total weight of the reaction mixture. It should be noted that at higher concentrations of PCR PS, the percent by weight solvent, based on the total weight of the reaction mixture, may generally be reduced.

The polymerization process conducted in the vessels or zones **300**, **302**, **304** may also include other materials such as co-polymers (e.g. synthetic rubbers such as polybutadiene, elastomers), plasticizers (e.g. mineral oil); flow promoters, lubricants, antioxidants (e.g., hindered phenolic antioxidant octadecyl 3,5-di(tert)-butyl-4-hydroxyhydrocinnamate), initiators, mold release agents (e.g. metal carboxylates or metal salts of fatty acids such as zinc stearate), color enhancers (e.g. 1-hydroxy-4-(methylphenyl)aminoanthraquinone) or polymerization aids such as chain transfer agents (e.g. alkyl mercaptans such as n-dodecyl mercaptan, terpenes such as terpinolene, alkyl and aryl halides, and alkyl aromatics). Other such additives that may be incorporated into the polymerization process for styrene resin production are also presently contemplated, are readily apparent to those of skill in the art, and are within the scope of the present disclosure. Indeed, any one or a combination of such components may be provided as a portion of the feed **18** provided to the initial vessel or zone **300** or via the injection ports **310**, **312**, **314** to vessels or zones **300**, **302**, **304**.

In accordance with present embodiments, the conditions within the vessels or zones **300**, **302**, **304** may be selected so as to produce a desired molecular weight range for the virgin styrenic resin, which may be determined based upon a particular combination of residence time and production rate. The residence time may be determined based at least partially upon the rate at which the reaction mixture is motivated through the vessels or zones **300**, **302**, **304**, while the reaction rate may be determined based at least partially on the temperature within each of the vessels or zones **300**, **302**, **304**. Generally, the temperature set point of each of the vessels or zones **300**, **302**, **304** may be set to between approximately 60° C. and 190° C. Because thermal initiation, which occurs between approximately 120° C. and 180° C., is a generally undesirable process, it may be desirable to choose a temperature set point for each of the vessels or zones **300**, **302**, **304** appropriate to avoid such initiation. By way of non-limiting example, the temperature set points of the vessels or zones **300**, **302**, **304** may generally be between approximately 80° C. and 180° C. Indeed, a temperature of the reaction mixture may be incrementally increased as it moves through the vessel/zone or plurality of vessels or zones **300**, **302**, **304** from between approximately 25° C. and 90° C. to between approximately 135° C. and 180° C.

It should be noted that the temperature set points of the vessels or zones **300**, **302**, **304** may be the same, or may be different. In embodiments where the vessels or zones **300**, **302**, **304** are zones of a tower or stratified reactor, there may be a thermal gradient from the initial zone **300** to the final zone **304**, with the initial zone **300** having a lower temperature set point compared to the final zone **304**. For example, the temperature difference between immediately adjacent zones may be between approximately 1° C. and 10° C., such as between approximately 2° C. and 8° C. Such a configuration may be desirable to maintain a relatively constant reaction rate and heat-generation rate between the zones. Finally, the temperatures may be chosen so as to obtain a desired reaction rate suitable for producing styrenic polymer chains having a desired length. It should also be noted that, in certain embodiments, a preheater may be utilized upstream of the initial zone **300** (or the initial zone **300** may be used as a preheater) having a temperature set point sufficient to activate the initiator. In this way, chemical initiation occurs at the beginning stages of the overall polymerization process and dominates the overall process, even at temperatures at which thermal initiation may occur to some extent.

IV. The Post-Consumer Containing (PCC) Styrenic Resin

As discussed above with respect to FIG. **1**, the reactor effluent **32** may be treated by the effluent treatment system **34** to remove volatiles (e.g. unreacted monomer, solvent) to isolate the polymer melt **38**, which is a styrenic resin having both the PCR PS from the PCR PS feed **22** and the virgin styrenic resin produced in the reactor system **28** from the MVA monomer **16**. The polymer melt **38** may also include a variety of additives to enhance the stability, appearance, and processability of the polymer melt **38**, including colorants, antiblocking agents, fire retardants, antioxidants, mold release agents, and the like. Any suitable amount of these and other additives may be incorporated into the polymer melt **38**, with the amounts being determined based upon the particular end use of the polymer melt **38**, various regulatory standards (e.g., standards for children's toys, food contact, and/or fire resistance), and the particular physical and chemical properties of the styrenic resin itself. Indeed, such amounts will be readily apparent to those of skill in the pertinent field and are within the scope of the present disclosure.

The amount of PCR PS incorporated into the polymer melt **38** will be primarily determined based upon the amount of PCR PS **14** provided to the dissolver system **94** of FIG. **3**, the amount of MVA monomer **16** provided to the dissolver system **94**, and the amount of any additional MVA monomer **16** or other styrenic-resin producing components provided to the reactor system **28** of FIGS. **1** and **5**. Thus, the amount of PCR PS in the polymer melt **38** may be determined by a simple mass balance calculation using the amount of PCR PS **14** initially provided the first and second dissolvers **120**, **122** (FIG. **3**) and the amount of PCR PS **14** remaining in the first and second dissolvers **120**, **122** after the dissolved mixture **124** is provided to the filter system **200** (FIG. **4**), which determines the actual concentration of PCR PS **14** in the dissolved mixture **124**. By way of example, the mass balance may be calculated according to equations (1)-(5), which are provided below.

$$\%\ \text{PCR PS}=\text{PCR PS Feed}/[\text{Total Feed Rate}-\text{Recycle Out}] \tag{1}$$

$$\text{PCR PS Feed}=\text{PCR PS Solution Flow Rate}\times\text{PCR Concentration in Dissolver} \tag{2}$$

$$\text{PCR Concentration in Dissolver}=\text{Weight of PCR PS Added}/[\text{Weight of MVA Monomer Added}+\text{Weight of PCR PS Added}] \tag{3}$$

$$\text{Total Feed}=\text{Feed of MVA Monomer}+\text{Feed of PCR PS Solution}+\text{Recycle Flow Rate}+\text{Additives Flow Rate} \tag{4}$$

$$\text{Recycle Out}=\text{Flow Rate of Recycle to Storage Tank} \tag{5}$$

The concentration of the PCR PS **14** in the MVA monomer **16** may be adjusted based on the amount of any additional feed components used to produce the PCR PS feed **22** (FIG. **4**). Using a known feed rate of the PCR PS feed **22** (or the reactor feed **26** having the PCR PS feed **22**), a known amount of PCR PS is provided to the reactor **28**. Accordingly, the concentration of PCR PS in the polymer melt **38** may be determined by simply dividing the amount of PCR PS provided to the reactor system **28** by the total weight of dry polymer melt **38** obtained after devolatilization and removal of any liquids.

Generally, the polymer melt **38** (i.e., PCC styrenic resin) may have between 1 weight percent and 50 weight percent PCR PS incorporated therein, such as between 1 weight percent and 40 weight percent PCR PS, or between 1 weight percent and 30 weight percent PCR PS. However, it will be appreciated that several factors may affect this concentration, including the ability to motivate the dissolved mixture **124** through the system **10** (FIG. **1**) as the dissolved mixture **124** increases in viscosity with increasing PCR PS concentrations. Limitations of the system **10** may be determined primarily by system equipment limitations, such as viscosity limitations for pumps, impellers, mixers, agitators and similar equipment. In addition, the ultimate end use for the styrenic resin may determine the maximum level of PCR PS, which typically has relatively poor physical properties, which can be incorporated into the PCC styrenic resin while still maintaining properties that are suitable for the end use. For example, melt flow rate (MFR), which is related to the processability and toughness of the PCC styrenic resin (higher values meaning easier processability but reduced toughness and stability), may be increased and the extensional viscosity (EV) of the PCC styrenic resin, which is generally related to processability and performance, may generally be reduced, with increasing amounts of PCR PS. While generally any MFR is presently contemplated, in some embodiments, such an increase in MFR and decrease in EV is generally undesirable, as high MFR (e.g. above about 5 g/10 min per ASTM-D1238-10) and low EV (e.g. below about 240,000 Pascal-seconds at 172° C. and an extension rate of 10 sec^{-1} and 0.3 seconds when measured on an extensional rheometer) may be associated with a generally low quality styrenic resin that will result in the production of a low quality article of manufacture.

Due at least in part to the PCR PS feed preparation system **20**, which is configured to produce a high quality feed of PCR PS in the MVA monomer, as well as the relatively good physical properties of the virgin styrenic resin produced within the reactor system **28**, present embodiments provide for the production of a PCC styrenic resin having between approximately 1 weight percent and 50 weight percent PCR PS, between 1 weight percent and 40 weight percent PCR PS, or between 1 weight percent and 30 weight percent PCR PS, and that is suitable for the production of articles of manufacture. However, the use of PCR PS in any amount is presently contemplated in accordance with present embodiments. By way of non-limiting example, the PCC styrenic resin produced in accordance with present embodiments may have between approximately 10 weight percent and 40 weight percent PCR PS, between approximately 15 weight percent and 35 weight percent PCR PS, between approximately 20 weight percent and 30 weight percent PCR PS, or approximately 25 weight percent PCR PS.

In still further embodiments, the PCC styrenic resin produced in accordance with present embodiments may have less than approximately 10 weight percent PCR PS and greater than approximately 1 weight percent PCR PS, such as between approximately 1 weight percent and 10 weight percent PCR PS, between approximately 1 weight percent and 9 weight percent PCR PS, between approximately 2 weight percent and 8 weight percent PCR PS, between approximately 3 weight percent and 7 weight percent PCR PS, between approximately 4 weight percent and 6 weight percent PCR PS, or approximately 5 weight percent PCR PS. In still further embodiments, the PCC styrenic resin produced in accordance with present embodiments may have greater than approximately 10 weight percent PCR PS and less than 20 weight percent PCR PS, such as between approximately 11 weight percent and 20 weight percent PCR PS, between approximately 12 weight percent and 18 weight percent PCR PS, between approximately 13 weight percent and 17 weight percent PCR PS, between approximately 14 weight percent and 16 weight percent PCR PS, or approximately 15 weight percent PCR PS.

With respect to the MFR of the PCC styrenic resin, as may be appreciated, the MFR generally increases with increasing PCR PS levels due to the poor (i.e., relatively high) MFR inherent to the PCR PS. In accordance with the present disclosure, all MFR values are quoted as values obtained in accordance with ASTM D-1238-10 using a 5 kg load measured at 200° C. Generally, the PCC styrenic resin will have a MFR of approximately 4 or less g/10 min, such as between approximately 1.2 g/10 min and 4.0 g/10 min. In accordance with present embodiments, a PCC styrenic resin having about

10 weight percent or less PCR PS may have a MFR of less than about 1.7 g/10 min. For example, in embodiments where the PCC styrenic resin has between approximately 1 weight percent and 9 weight percent PCR PS (e.g., between approximately 2 weight percent and 8 weight percent PCR PS, or between approximately 4 weight percent and 6 weight percent, such as approximately 5 weight percent PCR PS), the resin may have a MFR of less than 2.0 g/10 min, such as between approximately 1.2 g/10 min and 2.0 g/10 min, between approximately 1.2 g/10 min and 1.8 g/10 min, between approximately 1.3 g/10 min and 1.7 g/10 min, or between approximately 1.4 g/10 min and 1.6 g/10 min. In certain embodiments, the PCC styrenic resin may have between 20 and 30 weight percent PCR PS and may have a MFR of between approximately 1.6 g/10 min and 3.6 g/10 min. In another embodiment, the PCC styrenic resin may have between approximately 20 and 30 weight percent PCR PS and a MFR of approximately 2.5 g/10 min or less.

As another example, in embodiments where the PCC styrenic resin has between approximately 10 weight percent and 20 weight percent PCR PS, the resin may have a MFR of 2.5 g/10 min or less, such as between approximately 1.3 g/10 min and 2.0 g/10 min. In embodiments where the PCC styrenic resin has between approximately 20 weight percent and 26 weight percent PCR PS, the resin may have a MFR of 2.3 g/10 min or less, such as between approximately 1.6 g/10 min and 2.2 g/10 min or, in certain embodiments, 2.0 g/10 min or less. In further embodiments, the PCC styrenic resin may have between approximately 24 weight percent and 26 weight percent PCC styrenic resin with a MFR of between approximately 2.3 g/10 min and 1.8 g/10 min, or approximately 2.2 g/10 min or less, 2.1 g/10 min or less, 2.0 g/10 min or less, 1.9 g/10 min or less, or 1.8 g/10 min or less, depending on the quality of the PCR PS and the virgin styrenic resin incorporated into the PCC styrenic resin. Indeed, in certain embodiments, the PCC styrenic resin, at a concentration of approximately 25 weight percent PCR PS, may have a MFR of between approximately 1.8 g/10 min and 2.0 g/10 min.

The Z+1 molecular weight (Mz+1) of the PCC styrenic resin is one indicator of the processability and the performance (e.g., toughness, flexibility) of the resin. Mz+1 may be particularly indicative of these properties due to its emphasis on longer molecular weight chains, which are believed to increase strength and enable better orientation between polymer chains compared to resins having shorter polymer chains. Indeed, it is believed that the low Mz+1 of typical PCR PS resins leads to high MFR values, brittleness, lower strength, poor sidewall distribution in thermoformed products, and the like. Generally, higher Mz+1 values are indicative of a relatively higher population of long polymeric chains. The Mz+1 value of a resin may be obtained using size exclusion chromatography (SEC) techniques such as gel permeation chromatography (GPC). By way of non-limiting example, the Mz+1 value may be measured according to ASTM D-5296-11, including the methods described in U.S. Pat. Nos. 4,585,825, 5,191,040, and 6,545,090, all of which are incorporated by reference herein in their entirety for all purposes. All Mz+1 values quoted herein are atomic mass units (a.m.u.). As discussed herein, the Z+1 average molecular weight is generally defined according to equation (6) below:

$$M_{Z+1} = \frac{\sum n_i M_i^4}{\sum n_i M_i^3} \tag{6}$$

where M_i is the molecular weight of a given chain and n_i is the number of chains having the particular molecular weight

In accordance with present embodiments, the PCC styrenic resin having at least approximately 20 weight percent PCR PS may have an Mz+1 of at least approximately 665,000, at least approximately 670,000, at least approximately 680,000, at least approximately 685,000, at least approximately 690,000, at least approximately 700,000, or at least approximately 710,000 or more. Indeed, in certain embodiments, the Mz+1 of the PCC styrenic resin may be between approximately 670,000 and 750,000. For example, in embodiments where the PCC styrenic resin has between 20 weight percent and 30 weight percent PCR PS, the Mz+1 may be between approximately 685,000 and 740,000, such as between approximately 690,000 and 720,000, or between approximately 700,000 and 710,000. In one embodiment, the Mz+1 may be greater than approximately 695,000.

As a further example, in embodiments where the PCC styrenic resin has between 1 weight percent and 9 weight percent PCR PS, such as between approximately 2 weight percent and 8 weight percent PCR PS, or between approximately 4 weight percent and 6 weight percent PCR PS, such as approximately 5 weight percent PCR PS, the PCC styrenic resin may have an Mz+1 of at least approximately 680,000, at least approximately 690,000, at least approximately 700,000, at least approximately 710,000, or at least approximately 720,000. For example, in embodiments where the PCC styrenic resin has between 2 weight percent and 8 weight percent PCR PS, the Mz+1 may be between approximately 680,000 and 750,000, such as between approximately 700,000 and 750,000. For example, the PCC styrenic resin may have between 3 weight percent and 7 weight percent PCR PS, or between approximately 4 weight percent and 6 weight percent PCR PS, and may have an Mz+1 of between approximately 700,000 and 740,000, between or between approximately 710,000 and 730,000. In some embodiments, the PCC styrenic resin has between approximately 3 weight percent and 7 weight percent PCR PS, such as between approximately 4 weight percent and 6 weight percent PCR PS, and has an Mz+1 of between approximately 700,000 and 730,000.

The extensional viscosity (EV) of the PCC styrenic resin may provide a similar indication as to the processability and performance of the resin, such as its ability to provide adequate sidewall distribution in thermoformed articles, the use of the resin in regrind processes, and generally good orientation in sheet extrusion processes. The EV of the PCC styrenic resin may be measured using an extensional rheometer. The values quoted herein are intended to denote the values obtained on such a rheometer having an extensional viscosity fixture using an extension rate of 10 sec^{-1} at 172° C., with the value being recorded at 0.3 seconds.

As noted above, higher EV values may be desirable for the PCC styrenic resin. In accordance with present embodiments, the EV of the PCC styrenic resin may be at least approximately 250,000 Pascal-seconds (Pa-sec), such as at least approximately 270,000 Pa-sec, at least approximately 280,000 Pa-sec, at least approximately 290,000 Pa-sec, or at least approximately 300,000 Pa-sec. By way of non-limiting example, the PCC styrenic resin may have between approximately 20 weight percent and 30 weight percent PCR PS and an EV of at least approximately 285,000, Pa-sec, such as between approximately 285,000 Pa-sec and 320,000 Pa-sec, between approximately 290,000 Pa-sec and 315,000 Pa-sec, or between approximately 295,000 Pa-sec and 310,000 Pa-sec. In one embodiment, the PCC styrenic resin may have at least approximately 20 weight percent PCR PS and an EV of at least approximately 290,000 Pa-sec. For example, the PCC styrenic resin may have approximately 25 weight percent PCR PS and an EV of at least approximately 293,000 Pa-sec.

In other embodiments, the PCC styrenic resin may have between approximately 1 weight percent and 9 weight percent PCR PS and an EV of at least approximately 300,000, Pa-sec. For example, in embodiments where the PCC styrenic resin has between approximately 2 weight percent and 8 weight percent PCR PS, such as between approximately 3 weight percent and 7 weight percent, or between approximately 4 weight percent and 6 weight percent PCR PS, such as approximately 5 weight percent PCR PS, the EV of the PCC styrenic resin may be between approximately 300,000 Pa-sec and 350,000 Pa-sec, between approximately 310,000 Pa-sec and 340,000 Pa-sec, or between approximately 320,000 Pa-sec and 330,000 Pa-sec. In one embodiment, the PCC styrenic resin may have between approximately 3 weight percent and 7 weight percent PCR PS and an EV of at least approximately 320,000 Pa-sec. For example, the PCC styrenic resin may have between approximately 4 weight percent and 6 weight percent PCR PS (e.g., approximately 5 weight percent PCR PS) and an EV of between approximately 320,000 Pa-sec and 340,000 Pa-sec.

EXAMPLES

The following actual examples are set forth to provide those of ordinary skill in the art with a detailed description of how the techniques discussed herein may be implemented, and are not intended to limit the scope of the present disclosure.

Unless stated otherwise, the styrenic resins discussed herein were produced according to a free-radical solution polymerization process using an organic peroxide initiator, styrene monomer, various sources of PCR PS, and ethylbenzene solvent in a stratified reactor. The stratified reactor included nine polymerization zones capable of being placed at individual temperature set points. The individual set points formed a temperature gradient from approximately 108° C. to approximately 141° C. Agitation rates were controlled between 1 and 21 rotations per minute (rpm), with three separate agitators rotating at different rates. The resins were collected by multi-stage flashing and devolatilization at various times throughout the polymerization process, as is evident from the tables set forth below. An example set of parameters is provided in Table 1 below.

TABLE 1

Reaction Profile

Parameter	Units	Value
Total feed rate	lb/h	9000
Ethylbenzene in feed	%	10.5
Recycle to zones	lb/h EB	110
Initiator	ppm	275
Zn stearate	%	0.06
Color tint	ppm	725
preheater	° C.	85
Z1	° C.	108
Z2	° C.	114
Z3	° C.	116
Z4	° C.	118
Z5	° C.	120
Z6	° C.	123
Z7	° C.	129
Z8	° C.	133
Z9	° C.	141
1st RPM	rpm	21
2nd RPM	rpm	17
3rd RPM	rpm	1
1st Flash Temperature	° C.	164
1st Flash Pressure	mm Hg	325
2nd Flash Temperature	° C.	242
2nd Flash Pressure	mm Hg	11

The following test methods were employed to determine certain of the physical and analytical properties of the PCC styrenic resins and other resins discussed herein. Melt flow rate (MFR) was measured using a Tinius Olson Extrusion Plastometer Melt Flow Measurement Apparatus, Model MP993, according to the test procedure ASTM D-1238-10 at 200° C. using a 5 kilogram (kg) load. Molecular weight calculations for the resins, including weight average molecular weight, Mw, number average molecular weight, Mn, Z-average molecular weight, Mz, and Z+1 average molecular weight, Mz+1, were determined by the gel permeation chromatographic techniques similar to those described by ASTM test method D-5296-11 (polystyrene standard). Extensional viscosity measurements were conducted using an ARES G-2® rheometer with an extensional viscosity fixture. Compression molded samples were prepared with a thickness of 0.7 mm, a width of 10 mm, and a length of 18 mm. The compression molded samples were tested at a temperature of 172° C. The extension rate was 10 sec^{-1}. Extensional viscosity data was recorded at 0.3 seconds.

The PCC styrenic resins discussed with respect to Examples 1-3 were all produced using NEXTLIFE RECYCLING SUSTAINABLE POLYSTYRENE® as the source of PCR PS, which was obtained from NextLife Recycling, LLC of Boca Raton, Fla. Characteristic specifications of this resin in pellet and flake form are provided in Table 2 below.

TABLE 2

Example PCR PS Properties

Parameter	Units	Natural Pellets	White Flake
Melt Flow Rate (MFR), g/10 min	g/10 min	7.39	6.97
Mn	a.m.u.	75,600	76,400
Mw	a.m.u.	218,100	219,400
Mz	a.m.u.	388,900	385,800
Polydispersity		2.89	2.87

Example 1

A styrenic resin having, as an overall average, 8.7 weight percent of PCR PS was produced according to the polymerization process described above. A filtered PCR PS feed was produced by first mixing flakes of NEXTLIFE RECYCLING SUSTAINABLE POLYSTYRENE® PCR PS with styrene monomer to produce a slurry, which was provided to a dissolver, where the PCR PS was allowed to dissolve in the styrene monomer. The resulting solution was then strained to remove gross contaminants and subsequently passed through a feed filter having a 200 micron screen size to remove undissolved fines. The resulting stream was provided to the polymerization reactor to produce the PCC styrenic resin having properties as set forth in Table 3 below. The various samples were obtained at different time points during the polymerization process. Regarding certain of the measurements, "b*" is a color measurement denoting the relationship between the yellowness and blueness of the resin, with positive values tending toward yellow hues and negative values tending toward blue hues. Yellowness Index (YI) is a measurement relating to how yellow the resin appears. Optical Control Systems' (OCS) Pellet Scanning System model PS-25c measures off-color particles such as black specks.

TABLE 3

Example 1 PCC styrenic resin Properties

	sample no.						
Parameter	1	2	3	4	5	6	7
% PC PS	3%	6%	9%	10%	10%	10%	10%
MFR (g/10 min)	1.45	1.55	1.67	1.65	1.67	1.50	—
Mw/1000 (a.m.u.)	—	293.0	292.0	288.2	285.0	292.0	295.3
Mn/1000 (a.m.u.)	—	119.0	118.0	116.1	114.0	119.0	120.5
Mw/Mn		2.45	2.46	2.48	2.50	2.44	2.45
b*	−1.16	3.40	6.17	8.02	8.68	9.32	—
YI	−3.49	7.20	13.33	19.24	19.24	20.49	—
OCS (mm^2/kg)	2.54	1.98	2.85	5.05	7.54	1.14	—

Example 2

A styrenic resin having, as an overall average, 23.4 weight percent PCR PS was produced according to the polymerization process described above, except for a modification to the process utilized to produce the feed to the reactor. The PCR PS was added, in flake form, via a hopper and star valve at approximately 8000 lb/hr (for a total of 53,000 lb of PCR PS), directly to a dissolver pre-loaded with styrene (120,000 lb) being agitated. The balance of styrene monomer was added to bring the contents to approximately 25% PCR solution. Agitation and dissolution was carried out for about 6.5 hours. The resulting dissolved solution was fed to strainers to remove gross contamination, then through a set of four feed filters (50-400 micron) to remove undissolved fines. The strainer included two 30-inch strainers in parallel, but only one used at a time. The filter bags used in the strainers were nylon monofilament Rosedale high-capacity bag filters with dimensions of $7\frac{1}{16}$" diameter and 32" length with 4.4 sq. ft of filtration surface area and a 4.6 gallon capacity obtained from Rosedale Products, Inc. of Ann Arbor, Mich. The pore size of the filter was 800 microns nominal (part number NMO800P2SS-H and NMU800P2SS-H). The main feed filters were a group of four Parker Hannifin filters of size: $20\frac{1}{16}$" ID×$36\frac{9}{16}$" L (S/N: 33187-19045) obtained from Parker Hannifin Corp. of Cleveland, Ohio.

The resulting filtered feed was provided to the reactor system, where the styrene was polymerized to produce a substantially continuous stream of PCR PS product. As noted above, a series of samples obtained at different times during the overall polymerization process were tested to produce the values set forth in Table 4 below. "Granulation" denotes granulation size measured in grams per 100 pellets. Certain of the data may be rounded to facilitate presentation.

TABLE 4

Example 2 PCC styrenic resin Properties

	sample no.										
Parameter	1	2	3	4	5	6	7	8	9	10	11
% PC PS	21.1%	21.1%	20.6%	19.6%	15.0%	23.3%	22.1%	23.3%	24.9%	24.3%	25.2%
Feed Rate	10000	10000	9000	9000	8000	7500	7500	7500	7000	7000	7000
MFR (g/10 min)	1.6	1.7	1.94	1.94	1.77	1.75	1.91	1.83	1.78	2.11	2.3
Mw/1000 (a.m.u.)	294	—	288	292	290	292	287	289	291	284	276
Mn/1000 (a.m.u.)	122	—	118	119	121	121	119	118	120	118	114
b	10.5	11.9	13.4	13.4	10	12.01	13.7	13.9	14.2	13.65	14.47
YI	23	25.6	29.4	29.2	21.4	26.0	29.8	30.5	31.2	30.3	33.4
Zn St (wt %)	0.08	—	0.09	0.09	0.082	0.086	0.089	0.09	0.09	0.09	0.11
OCS (mm^2/kg)	2.65	—	0.27	0.73	1.37	0.76	1	2.39	3.19	4.79	3.07
Granulation (g/100 pellets)	2.64	—	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.43	2.5

As can be seen from Table 4, the styrenic resin produced in this example contained between approximately 20 weight percent PCR PS and 25 weight percent PCR PS, with a MFR varying between 1.6 g/10 min and 2.3 g/10 min. The resin also incorporates, on average, about 0.09 weight percent zinc stearate (Zn St) as measured by X-ray fluorescence.

Example 3

A styrenic resin having, as an overall average, 24.4 weight percent of PCR PS was produced according to the polymerization process described above, except that the PCR PS was used in pellet form and all of the filter bags utilized for filtration of the feed were 400 micron filters. In addition, 100 lb of IRGANOX® 1076 hindered phenolic antioxidant, available from BASF SE of Ludwigshafen, Germany, was added to 60,000 lb of the dissolved mixture of PCR PS in styrene monomer to ascertain the affect of the antioxidant on the resulting resin. As can be appreciated from the tabulated data, the addition of antioxidant pre-reaction can reduce Mw and PDI, indicating that it may hinder the formation of higher molecular weight polystyrene chains. The properties resulting from the polymerization reaction are provided in Table 5 below. In samples 8 and 9 (denoted by the asterisk), the feed included the antioxidant. As a result of this test, and prior research, it was determined that the anti-oxidant should be added after polymerization.

TABLE 5

Example 3 PCC styrenic resin Properties

	sample no.								
Parameter	1	2	3	4	5	6	7	8*	9*
% PC PS	18.8%	21.0%	24.7%	24.5%	24.7%	24.6%	24.4%	24.8%	24.2%
Feed Rate	8000	9000	9000	9000	9000	9000	9000	9000	9000
MFR (g/10 min)	1.97	2.4	2.1	1.94	1.80	2.0	2.2	2.67	2.53
Mw/1000 (a.m.u.)	285	280	283	285	283	282	279	264	267
Mn/1000 (a.m.u.)	118	117	117	117	116	115	116	117	117
PDI	2.41	2.39	2.42	2.44	2.43	2.45	2.41	2.26	2.28
a*	0.3	2.10	2.99	2.3	2.4	2.99	3.2	3.34	3.3
b*	15.2	19.4	20.7	19.5	19.9	20.6	20.7	21.4	21.2
YI	35	46.5	51.56	47.4	48.1	50.8	51.6	53.4	52.3
Zn St ppm	700	800	900	900	900	800	900	900	900
OCS (mm^2/kg)	—	14.66	—	0.41	—	—	—	—	—

As can be appreciated from Table 5, the PCC styrenic resin produced according to this example contained between approximately 18 weight percent and 25 weight percent PCR PS, with a MFR of between approximately 2.0 g/10 min and 2.4 g/10 min.

Comparison of in-Reactor Produced PCC Styrenic Resin with Compounded Resin

As set forth above, it is recognized that PCC styrenic resins produced according to the in-reactor method discussed herein generally have better overall properties (e.g., as measured by MFR, molecular weight, i.e. Mw and Mz+1, and EV) than resins produced by compounding a virgin resin with the PCR PS resin in a similar ratio. For example, the in-reactor produced materials will generally have a lower MFR, a higher EV, and a higher Mz+1, even after a number of passes through an extruder. The compared resins set forth below include an in-reactor produced resin having 25 weight percent PCR PS, a compounded resin produced by compounding virgin polystyrene resin with flakes of the PCR PS resin in a weight ratio of 75:25 virgin polystyrene to PCR PS, and a compounded resin produced by compounding virgin polystyrene resin with pellets of the PCR PS resin in a weight ratio of 75:25 virgin polystyrene to PCR PS. The virgin styrenic resin used was STYRON® 685D polystyrene, which is commercially available from Americas Styrenics LLC of the Woodlands, Tex.

The compounded resins were produced by compounding in a HaakeBuchler Rheocord System 40 with model 23-50-000 twin screw extruder attached. The resins were mixed in four zones (zones 1-4) at 160 rpm, with the temperature of zones 1-4 being 180° C., 190° C., 200° C., and 210° C., respectively.

The in-reactor produced PCC styrenic resin used for the comparison was obtained from a portion of the materials produced in the polymerization process set forth in Example 2. Properties of these resins are provided below in Tables 6-8. "L*," "a*," and "b*" are Tristimulus color measurements based on CIE (Comission Internationale de l'Eclairage or International Comission on Lighting) "L*,a*,b*" scale developed in 1976. "L*" measures the lightness of the object (with 0=black, 100=white) and "a*" measures the red/green hue (red being positive values and green represented by negative values).

TABLE 6

In-Reactor 25% PCR PS

	Sample					
Parameter	PCC Styrenic Resin	Pass 1	Pass 3	Pass 5	Pass 7	Units
MFR	2.21	2.48	3.03	3.36	3.93	g/10 min.
Mn	113,400	111,400	108,500	104,400	101,400	a.m.u.
Mw	274,700	268,500	257,900	247,300	240,600	a.m.u.
Mz	471,000	457,000	435,900	416,600	403,800	a.m.u.
PDI	2.42	2.41	2.38	2.37	2.37	
Mz + 1	690,000	665,900	631,100	602,600	582,800	a.m.u.
EV	292,906	273,412	245,166	235,481	217,289	Pa-sec
a*	−1.34	−1.49	−1.75	−1.91	−2.09	
b*	14.16	14.81	16.06	17.26	18.66	
YID	27.2	28.1	30.1	32.0	34.3	

TABLE 7

75% Virgin STYRON ® 685D/25% PCR PS Flake

Parameter	Sample Initial Compounding	Pass 1	Pass 3	Pass 5	Pass 7	Units
MFR	2.83	3.00	3.47	3.74	4.26	g/10 min.
Mn	114,000	109,400	105,500	101,200	100,600	a.m.u.
Mw	277,500	270,300	263,700	253,000	246,700	a.m.u.
Mz	463,700	452,300	440,700	420,000	407,900	a.m.u.
Polydispersity	2.43	2.47	2.50	2.50	2.45	
Mz + 1	664,900	647,700	630,300	597,000	578,600	a.m.u.
EV	259,881	240,090	222,132	217,356	201,270	Pa-sec
L*	76.26	76.15	75.93	75.59	75.25	
a*	−1.91	−1.79	−1.97	−1.84	−2.01	
b*	11.99	13.00	14.30	15.16	16.94	
YID	24.7	26.8	29.3	31.2	34.6	

TABLE 8

75% Virgin STYRON ® 685D/25% PCR PS Pellets

Parameter	Sample Initial Compounding	Pass 1	Pass 3	Pass 5	Pass 7	Units
MFR	2.85	3.12	3.52	3.94	4.30	g/10 min.
Mn	108,900	109,400	106,400	101,200	100,400	a.m.u.
Mw	272,700	269,000	259,200	249,500	243,300	a.m.u.
Mz	458,400	450,600	431,700	414,100	402,100	a.m.u.
Polydispersity	2.50	2.46	2.44	2.47	2.42	
Mz + 1	658,400	645,700	615,800	589,100	570,700	a.m.u.
EV	250,455	242,657	225,295	217,727	197,070	Pa-sec
L*	76.46	76.30	76.10	75.94	75.75	
a*	−0.82	−0.93	−1.18	−1.39	−1.44	
b*	12.02	13.22	15.37	17.77	19.11	
YID	25.7	28.1	32.1	36.5	39.1	

As can be seen in Tables 6-8 above, in addition to the properties of the resins post-production (labeled as "PCC styrenic resin" and "initial compounding"), their respective properties are also listed after several passes through an extruder. Indeed, the data suggests that in-reactor produced resins have, generally, a higher population of high molecular weight chains (as reflected by higher Mz+1 values), higher EV values, and lower MFR values when compared to resins produced by compounding. Therefore, the in-reactor produced resins will generally perform better than compounded resins in applications where good sidewall distribution, orientation, and chain entanglement are desired.

The data also suggests that the in-reactor produced resins may better maintain their properties upon processing compared to the compounded resins. Indeed, as can be seen when comparing the Mz+1, MFR, and EV across the multiple passes through the extruder, the in-reactor produced resin is superior in these measures throughout the seven passes. Indeed, PCC styrenic resins produced in accordance with present embodiments may not only have properties suitable for the production of various articles of manufacture, but may also advantageously enable enhanced properties in a subsequently produced PCC styrenic resin. In other words, the PCC styrenic resin may eventually serve as a source of PCR PS and, in doing so, may provide enhanced properties to a subsequently produced or "second generation" PCC styrenic resin produced therefrom when compared to a PCC styrenic resin produced by compounding.

Example 4

A styrenic resin having, as an overall average, approximately 5 weight percent of PCR PS was produced according to the polymerization process described above, except that the PCR PS is different than as described above, and the reaction profile was adjusted. The reaction profile is set forth in Table 9 below, and example properties of the PCR PS are provided in Table 10 below. It should be noted that the reaction profile set forth in Table 9 represents an increase in production rate of the reactor system, as demonstrated by an increase in the temperature in certain of the zones of the reactor and the feed rate into the reactor.

TABLE 9

Reaction Profile

Parameter	Units	Value
Total feed rate	lb/h	10000
Ethylbenzene in feed	%	6.2
Recycle to zones	lb/h EB	140
Initiator	ppm	310
Zn stearate	%	0.07
Color tint	ppm	425
preheater	° C.	85
Z1	° C.	112
Z2	° C.	114
Z3	° C.	117

TABLE 9-continued

Reaction Profile		
Parameter	Units	Value
Z4	° C.	122
Z5	° C.	125
Z6	° C.	129
Z7	° C.	130
Z8	° C.	131
Z9	° C.	132
1st RPM	rpm	21
2nd RPM	rpm	14
3rd RPM	rpm	1
1st Flash Temperature	° C.	185
1^{st} Flash Pressure	mm Hg	410
2^{nd} Flash Temperature	° C.	250
2nd Flash Pressure	mm Hg	11

Provided in Table 10 below are certain properties of the PCC styrenic resin having approximately 5% by weight PCR PS produced as an in-reactor resin, as well as comparative data listing the properties for a PCC styrenic resin having approximately 5% by weight PCR PS produced via compounding. Data corresponding to the materials used to produce the resins, specifically the PCR PS, is also provided. In Table 10, the data is rounded to the nearest hundred. The virgin material used to produce the compounded resin was STYRON® 685D polystyrene.

TABLE 10

In-Reactor 5% PCC Styrenic Resin and Compounded 5% PCC Styrenic Resin

Parameter	In-Reactor PCC Styrenic Resin	Compounded PCC Styrenic Resin	PCR PS	Units
Unconditioned MFR	1.55	2.07	7.43	g/10 min.
Conditioned MFR	1.47	1.97	7.31	g/10 min.
Mn	130,100	117,500	92,400	a.m.u.
Mw	299,800	289,900	216,500	a.m.u.
PDI	2.31	2.47	2.34	
Mz	492,780	479,700	369,400	a.m.u.
Mz + 1	703,000	687,000	535,300	a.m.u.
EV	328,578	282,154	127,938	Pa-sec

As shown in the data above, the PCC styrenic resin produced according to present embodiments (in-reactor) has better overall properties compared to the compounded resin. Accordingly, the present techniques provide PCC styrenic resins having improved properties that are realized even at relatively low loadings of recycled material. In other words, the properties of the PCC styrenic resins produced using the in-reactor techniques disclosed herein are superior to the properties obtained via compounding techniques, even when relatively small amounts of recycled styrenic resins are incorporated into the styrenic resins produced as a final product. It should be noted that the process used to produce the in-reactor PCC styrenic resin of Example 4 also incorporated the use of self-cleaning filters in preparing the PCR PS feed provided to the reactor.

The specific embodiments described above have been shown by way of example, and it should be understood that these embodiments may be susceptible to various modifications and alternative forms. It should be further understood that the claims are not intended to be limited to the particular forms disclosed, but rather to cover all modifications, equivalents, and alternatives falling within the spirit and scope of this disclosure.

What is claimed is:

1. A styrenic resin comprising between approximately 1 weight percent and 9 weight percent post-consumer recycle polystyrene (PCR PS), wherein the styrenic resin has a melt flow rate (MFR) of less than approximately 2.0 g/10 min per ASTM D-1238-10 and an Mz+1 of at least approximately 700,000.

2. The styrenic resin of claim **1**, wherein the styrenic resin has a MFR of between approximately 1.2 g/10 min and 1.9 g/10 min per ASTM D-1238-10.

3. The styrenic resin of claim **1**, wherein the styrenic resin comprises between approximately 2 and 8 weight percent PCR PS and has a MFR of between approximately 1.3 g/10 min and approximately 1.7 g/10 min per ASTM D-1238-10.

4. The styrenic resin of claim **1**, wherein the styrenic resin comprises between approximately 4 and 6 weight percent PCR PS and has a MFR of between approximately 1.4 g/10 min and approximately 1.6 g/10 min per ASTM D-1238-10.

5. The styrenic resin of claim **1**, wherein the styrenic resin has between approximately 2 and 8 weight percent PCR PS and an Mz+1 of between approximately 700,000 and 750,000.

6. The styrenic resin of claim **1**, wherein the styrenic resin has an extensional viscosity of at least 300,000 Pascal-seconds (Pa-sec) when measured on an extensional rheometer at 172° C. at an extension rate of 10 sec^{-1} and a measurement recording time at 0.3 seconds.

7. The styrenic resin of claim **1**, wherein the styrenic resin has an extensional viscosity of between approximately 300,000 Pa-sec and approximately 350,000 Pa-sec when measured on an extensional rheometer at 172° C. and an extension rate of 10 sec^{-1} and a measurement recording time at 0.3 seconds.

8. The styrenic resin of claim **1**, wherein the styrenic resin has between approximately 4 and 6 weight percent PCR PS, has an MFR of between approximately 1.4 and 1.6 g/10 min per ASTM D-1238-10, has an Mz+1 of between approximately 700,000 and 730,000, and an extensional viscosity of between approximately 320,000 and 340,000 Pa-sec when measured on an extensional rheometer at 172° C. at an extension rate of 10 sec^{-1} and a measurement recording time at 0.3 seconds.

9. The styrenic resin of claim **1**, wherein the styrenic resin is formed by a process comprising:

providing the PCR PS and monovinylarene monomer to a dissolver;

mixing the PCR PS and monovinylarene monomer within the dissolver to dissolve the PCR PS in the monovinylarene monomer so as to produce a first mixture;

providing the first mixture to a filter system comprising a self-cleaning filter to remove polymeric contaminants from the first mixture to produce a filtered mixture;

producing a reaction mixture comprising the filtered mixture; and

subjecting the reaction mixture to free-radical solution polymerization conditions to produce the styrenic resin.

10. An article of manufacture produced using a styrenic resin comprising between approximately 1 weight percent and 9 weight percent post-consumer recycle polystyrene (PCR PS), wherein the styrenic resin has a melt flow rate (MFR) of less than approximately 2.0 g/10 min per ASTM D-1238-10 and an Mz+1 of at least approximately 700,000.

11. The article of manufacture of claim **10**, wherein the styrenic resin has between approximately 4 and 6 weight percent PCR PS, has an MFR of between approximately 1.4 and 1.6 g/10 min per ASTM D-1238-10, has an Mz+1 of between approximately 700,000 and 730,000, and an extensional viscosity of between approximately 320,000 and 340,000 Pa-sec when measured on an extensional rheometer at 172° C. at an extension rate of 10 sec^{-1} and a measurement recording time at 0.3 seconds.

12. A method of producing a styrenic resin having post-consumer recycle polystyrene (PCR PS), comprising:

providing PCR PS and monovinylarene monomer to a dissolver;

mixing the PCR PS and the monovinylarene monomer within the dissolver to at least partially dissolve the PCR PS in the monovinylarene monomer in order to produce a first mixture;

providing the first mixture to a filter system comprising a self-cleaning filter to remove polymeric contaminants from the first mixture to produce a filtered mixture;

producing a reaction mixture comprising the filtered mixture; and

subjecting the reaction mixture to free-radical solution polymerization conditions to produce the styrenic resin having the PCR PS.

13. The method of claim **12**, wherein the PCR PS and the monovinylarene monomer are provided to the dissolver in an amount such that the styrenic resin has between approximately 1 weight percent and 30 weight percent PCR PS.

14. The method of claim **12**, wherein the styrenic resin comprises between approximately 1 weight percent and 9 weight percent post-consumer recycle polystyrene (PCR PS), and has a melt flow rate (MFR) of less than approximately 2.0 g/10 min per ASTM D-1238-10 and an Mz+1 of at least approximately 700,000.

15. The method of claim **14**, wherein the styrenic resin has a MFR of between approximately 1.2 g/10 min and 1.9 g/10 min per ASTM D-1238-10.

16. The method of claim **14**, wherein the styrenic resin has between approximately 4 and 6 weight percent PCR PS, has an MFR of between approximately 1.4 and 1.6 g/10 min per ASTM D-1238-10, has an Mz+1 of between approximately 700,000 and 730,000, and an extensional viscosity of between approximately 320,000 and 340,000 Pa-sec when measured on an extensional rheometer at 172° C. at an extension rate of 10 sec^{-1} and a measurement recording time at 0.3 seconds.

17. The method of claim **12**, wherein the PCR PS and the monovinylarene monomer are provided to the dissolver in an amount such that the styrenic resin has between approximately 20 weight percent and 30 weight percent PCR PS.

18. The method of claim **12**, wherein providing the PCR polystyrene and the monovinylarene monomer to the dissolver comprises providing the PCR polystyrene to the dissolver as a solid and the monovinylarene monomer as a liquid, and wherein the mixing of the PCR polystyrene and the monovinylarene monomer in the dissolver is performed in an atmosphere substantially free of oxygen.

19. The method of claim **12**, comprising removing metal particulates from a flow comprising the PCR polystyrene using a magnetic separator disposed upstream of the dissolver.

20. The method of claim **12**, wherein producing the reaction mixture comprising the filtered mixture comprises providing a free-radical initiator, such that subjecting the reaction mixture to free-radical solution polymerization conditions comprises subjecting the reaction mixture to a chemically initiated free-radical polymerization.

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